# Neurological development in infancy

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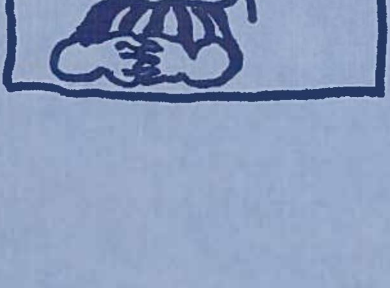
BERT TOUWEN

# NEUROLOGICAL DEVELOPMENT IN INFANCY



## ERRATA

Page 13 footnote: am grateful . . ., read: I am grateful . . .

Page 26 Group IV: A group of items which did not show . . .
read: A group of items which did show . . .

Page 34 Fifth line from above, table XI and XIII; read: table XII and XIV

Page 35 Third line from below, table XI and XIII; read: table XII and XIV

Page 37 Nineth line from below, 4 read 3

Page 38 First line above, 2 read 1
Seventh and eighth line from above, table X and XII;
read: table XI and XIII

Page 44 Sixth line from above, 2 and 4, read 1 and 3

Page 49 and 51 Exchange figures 10 and 11

Page 49 Seventh line from above, 10, 31 and 21, read 10, 34 and 24

Page 61 Heading: Recording: 2. wriggling . . ., read 1. wriggling . . .

Page 78 Table VII: first changes of standing up and of other items;
read: first changes of standing up and final changes of other items . . .

Page 88 First line, . . . final first changes . . .; read: final and first changes . . .

RIJKSUNIVERSITEIT TE GRONINGEN

# NEUROLOGICAL DEVELOPMENT IN INFANCY

**PROEFSCHRIFT**

TER VERKRIJGING VAN HET DOCTORAAT IN DE

GENEESKUNDE

AAN DE RIJKSUNIVERSITEIT TE GRONINGEN OP GEZAG VAN DE

RECTOR MAGNIFICUS

**DR. M. J. JANSSEN**

IN HET OPENBAAR TE VERDEDIGEN OP

WOENSDAG 8 OKTOBER 1975

DES NAMIDDAGS TE 2.45 UUR PRECIES.

DOOR

**BERT CHRISTIAAN LOUIS TOUWEN**

GEBOREN TE DEN HAAG

DRUKKERIJ GRASMEIJER & WIJNGAARD — GRONINGEN

*Promotor: Prof. Dr. H. F. R. Prechtl*

*Co-promotor: Prof. Dr. H. H. W. Hogerzeil*

STELLINGEN

I Bij de extrapolatie van neurologische verschijnselen en hun betekenis bij het zich ontwikkelende kind naar de volwassene en omgekeerd wordt ten onrechte kwalitatieve identiteit van het kinderlijke en volwassen zenuwstelsel geïmpliceerd.

II Leeftijdsnormen voor de kinderlijke funktie-ontwikkeling zijn slechts in beperkte mate bruikbaar voor de diagnostiek van hersenaandoeningen.

III Inconsistentie gedurende de ontwikkeling van de motoriek is een karakteristieke eigenschap van het gezonde zenuwstelsel.

IV De vraagstelling: „Veroorzaakt ondervoeding stoornissen in de ontwikkeling van het centrale zenuwstelsel?" gaat voorbij aan interacties tussen een toestand van ondervoeding en direct en indirect daarmee samenhangende andere omgevingsfaktoren. De vraagstelling dient dan ook te luiden: „Draagt ondervoeding bij tot het ontstaan van stoornissen in de ontwikkeling van het centrale zenuwstelsel?"

V Het instellen van fysiotherapeutische behandeling van motorische stoornissen dient niet te wachten tot een specifieke diagnose volgens een der klassifikaties van cerebrale paresen gesteld of uitgesloten is.

VI Gedurende de eerste levensjaren is er geen wezenlijk verschil tussen fysiotherapie, ergotherapie en logopedie. De opleidingen van fysiotherapeuten, ergotherapeuten en logopedisten dient hieraan te zijn aangepast.

VII Zolang er geen deugdelijke internationale overeenstemming bestaat over de definitie van hypoglycaemie in de zuigelingenperiode, is naonderzoek naar de gevolgen van hypoglycaemie in de eerste levensdagen zinloos.

VIII De door Raine voorgestelde glycine-medicatie bij de behandeling van een prolinemie type II heeft als bezwaar dat vooral in het pasgeborene-tijdperk de verhoogde concentratie van glycine in de weefsels een schadelijke bijwerking kan hebben.

IX Bij het stellen van de indicatie tot partus arte praematurus dienen intra- en extra-uterine risico's zorgvuldig tegenover elkaar te worden afgewogen. Vooral de laatste plegen te worden onderschat.

X Voor de beoordeling van de funktie ontwikkeling van een prematuur geborene dient diens kalenderleeftijd gecorrigeerd te worden voor de duur van de zwangerschap.

XI Het verschijnsel dat Nederland aan de top staat van de Europese landen wat betreft het jaarlijks aantal kinder-slachtoffers van het verkeer, dient o.m. de arts te stimuleren tot een aktieve houding ten aanzien van de nog steeds toe-nemende verkeersproblematiek.

XII Aan de omgang met patienten en de stervensbegeleiding wordt tijdens de opleiding tot arts en tot specialist te weinig aandacht besteed.

XIII De ambivalentie van vooral de oudere Engelse literatuur-kritiek ten aanzien van Joseph Conrad is ten dele te verklaren uit diens positie van Engels schrijvende niet-Engelsman.

XIV De arts dient zich met polemologie bezig te houden.

XV Ironie is de enige mogelijkheid tot overleven.

Stellingen behorende bij het proefschrift van B. C. L. Touwen.

8 oktober 1975.

*Jamais la nature ne nous livrerait ses secrets; elle n'avait pas de secrets; c'est nous qui inventions des questions, et qui façonnions ensuite des réponses: et jamais nous ne découvrions au fond de nos cornues que nos propres pensées; ces pensées pouvaient au cours des siècles se multiplier, se compliquer, former des systèmes de plus en plus vastes et subtils, jamais elles ne m'arracheraient à moi-même.*

*(Simone de Beauvoir, 1946)*

**CONTENTS**

## TABLES

## APPENDICES

Appendix A: Criteria for optimal obstetrical conditions.

Appendix B: Criteria for neonatal neurological optimality.

Appendix C: Means, standard deviations, coefficients of skewness and kurtosis for the items of group III, including speech development.

Appendix D: Correlation-coefficients ($p \leqq 0.01$) of the relationships between the first and final changes of the items of group III.

Appendix E: Correlation-coefficients ($p \leqq 0.01$) of the interrelationships of the first changes of the items of group III.

Appendix F: Correlation-coefficients ($p \leqq 0.01$) of the interrelationships of the final changes of the items of group III.

Appendix G: Correlation-coefficients ($p \leqq 0.01$) of the interrelationships of the developmental ranges of the items of group III.

Appendix H: Correlation-coefficients ($p \leqq 0.01$) of the relationships between the developmental ranges and the number of inconsistencies of the items of group III.

Appendix J: Variation ranges of the first and final changes and the number of inconsistencies of the items of group III.

# Chapter I Introduction

In the last few decades a periodical evaluation of the condition of infants has become customary. Besides general pediatric supervision and advice concerning feeding-quality and -schedule, also the condition of the nervous system has gradually become a focus of interest. This has been stimulated by several clinicians and physiotherapists who stated that early diagnosis of a deviant neurological development often minimalizes invalidation at older ages, because of timely treatment and parent-counseling.

Early diagnosis presupposes a neurological examination-technique, which enables the examiner to pronounce upon the integrity of the nervous system. As for such a technique the examiner must take into regard the specific properties of the infantile nervous system, and the technique should be based on knowledge of the neural mechanisms underlying the manifestations of nervous activity. In this respect a distinction should be made between the neonatal period and subsequent infancy, because much work has been done to illuminate the neurology of the former, while our knowledge of the neurology of subsequent infancy is considerably smaller.

Among the very first who paid attention to the newborn infant from a neurological point of view was André-Thomas. After a whole lifetime spent on adult neurology, he turned to the newborn infant at an age, at which the majority of people retire.
Because all his life he had worked with adult neurological patients, it is not surprising that his approach to newborn infants was strongly affected by his concepts of the adult nervous system. His work was of great value because it stressed the necessity of paying attention to the up till then rather neglected field of neonatal neurology (André-Thomas and St. Anne Dargassies, 1952).

Gradually it became clear that in dealing with an infant's nervous system knowledge of adult neurology was not sufficient. This is the reason why Prechtl based his extensive work on an ontogenetic concept, giving full credit to the specific properties of the infant's nervous system (see eg. Prechtl, 1956, 1960; Prechtl and Beintema, 1964). His work induced him to design a neurological examination technique for the fullterm newborn infant, and it stimulated further research on infancy and childhood, now called developmental neurology. Schulte's approach to neonatal neurology originated in neuro-physiology, especially that of the spinal cord, as is reflected in his chapter on the neurological development of the neonate in "Scientific Foundations of Paediatrics" (Davis and Dobbing, 1974).

Contrary to the extensive knowledge concerning the newborn infant, much less is known about the neural mechanisms and their developmental course throughout infancy, although Peiper (1961) was able to com-

**TABLE I**

**Some studies of infantile responses published after 1950**

| | |
|---|---|
| Babkin, P. S. (1960) | Foot sole response |
| Brain, R. and Wilkinson, M. (1959) | Foot sole response |
| Dietrich, H. F. (1957) | Foot sole response |
| Holt, K. S. (1961) | Foot sole response |
| Ingram, T. T. S. (1962) | Feeding reflexes |
| Lamote de Grignon, C. (1955) | Moro |
| Linden, J. (1969) | Plantar grasp |
| MacKeith, R. C. (1964) | Stepping movements |
| MacKeith, R. C. (1964) | Placing reactions |
| Mitchell, R. G. (1960) | Moro |
| Mitchell, R. G. (1962) | Landau |
| Paine, R. S., Brazelton, T. B., Donovan, D. E., Drorbaugh, J. E., Hubbell, J. P. and Sears, E. M. (1964) | Postural reactions |
| Paine, R. S. (1963) | Postural reactions |
| Parmelee Jr., A. M. (1964) | Moro |
| Poeck, K. (1968) | Palmar grasp |
| Prechtl, H. F. R. (1958) | Feeding reflexes |
| Twitchell, Th. E. (1970) | Palmar grasp |
| Vassella, F., and Karlsson, B. (1962) | Asymmetric tonic neck reflex |
| Wolff, P. H. (1968) | Sucking |
| Zapella, M. (1966) | Placing reactions |
| Zapella, M. (1967) | Placing reactions and plantar grasp |
| Zelazo, Ph. R., Zelazo, N. A. and Kolb, S. (1972) | Stepping movements |

pound a substantial volume on the development of the nervous system in infancy.

This valuable work contains a general survey of the litterature till about 1960, but it consists mainly of an encyclopedic collection of single neurological items. As the title of his book shows, ("Die Eigenart der kindlichen Hirntätigkeit") Peiper considered the infantile brain thoroughly different from the adult brain, but in his book he only records a collection of infantile reactions and responses.

The book lacks a critical evaluation and formulation of a methodological concept. It is, therefore, not surprising that Peiper did not believe in the possibility of a clinical neurological assessment of the infant (personal communication to Prechtl, 1957). Although a careful report of various studies is given in his book, little attention is paid to such issues as uniformity of definition, and standardization and operationalization of the methods. Thus it is very difficult for the reader to compare the results of the various studies. Furthermore, comparison with findings of more recent studies, such as listed in table I, is complicated by the differences in rearing attitudes consequent to differences in ideas of consecutive generations of parents and examiners.

Such a generation-effect may influence feeding-methods and -contents, health-care in general and modes of training and rearing during infancy, as is strikingly evident in the case of, for instance, prematures. The effect of such differences on the manifestations of nervous development is unknown. As for the studies listed in table I, operationalization, and standardization of technique and recording, as well as criteria for sampling of the subjects and definitions of the responses, are duly reported in the majority of cases. Nevertheless definitions and procedures often vary widely, which hampers comparison.
Like Peiper, McGraw (1943) was interested in the development of nervous functions, which she called "neuromuscular maturation". While Peiper restricted himself to collecting items without building up a specific frame of reference, McGraw started from a different angle.
She collected longitudinal data on the maturation of a set of motor items, such as posture and locomotion, and responses such as grasping and mororeactions. She then tried to explain the various and consecutive phenomena which she observed, with respect to the theoretical concept of "Cerebralization" or "Corticalization". This concept is partly based on Coghill's individualization theory (1929), partly on the morphological and histological brain studies of Tilney (1937, cited by McGraw) and Conel (1939, 1941, idem). Her work is still outstanding in its exquisite observation and description of changes occurring in several motor phenomena during development. McGraw did not intend to design a neurological examination, or to point the way to neurological diagnoses. She merely tried to comprehend the changing activity of the brain during development in the light of the ontogenetic ideas of her time.

Quite a different approach is to be observed in the work of Gesell, who was interested in the development of overt behaviour. He defined behaviour as an expression of activity of the nervous system. He stated explicitly that he studied the development of behaviour in order to arrive at a diagnosis of the developmental status of a child, which in his opinion reflected the degree of integrity of the child's nervous system. He interpreted deviant behavioural development in terms of neurological impairment, in accordance with his theory that behavioural development is based on innate mechanisms of maturation of the nervous system (Gesell, 1954).
Until to-day Gesell's work has had a great impact on many subsequent workers, such as Griffiths (1954), Illingworth (1966), Bayley (1969), Knobloch, Pasamanick and Sherard (1966), Frankenburg and Dodds (1967) and others.
It was his great merit that he showed that systematic and accurate observation and testing of infants yields important information about their functional development. But he did not offer an explicit formulation of the ways in which the nervous system generates behaviour. Therefore Gesell's technique for "developmental diagnosis" (Gesell and Armatruda, 1947) is not a neurological examination in the strict sense.

A recent approach to developmental testing with an implicit evaluation of the nervous system was forwarded by Zdànska-Brincken and Wolánski (1969). They described a graphic method for the evaluation of motor development, which has the merit of distinguishing gross functional areas of development such as respectively development in prone, supine and vertical position. However, they limited themselves to a mere description of functional development.

Summarizing we may conclude that the knowledge of the development of the nervous system during infancy is limited to scattered information about single items, but that a more profound understanding of the neural mechanisms during a child's development, especially after the newborn period, is still needed.

**Purpose of the present study**

To formulate the purpose of the study which is presented here, is as important as stating explicitly what it is not meant to be.

Firstly this study reports a descriptive analysis of the developmental course of a series of items, such as used in neurological and developmental assessment in infancy, especially during the first year of life.

Secondly an analysis of the changes occurring in the functional organization of the neural mechanisms throughout development will be forwarded: the developmental changes will be considered as the variables which may give insight into the organization of neural mechanisms.

For this purpose a group of low-risk infants has been selected carefully. Low-risk infants were chosen in order to minimalize a possible inclusion of infants with impaired nervous systems. In this group of infants the developmental course of a set of items is analysed, as well as the presence or absence of coherence. The results of this study will be useful for a better understanding of maturing brain mechanisms and, at a later stage, for the design of a technique for neurological diagnosis and developmental testing procedures.

The present study does not pretend to give norms for the neurological development in infancy, as the size and selection of the group of infants precludes the use of the results as normative data. Neither does it suggest a design for the neurological examination. It merely presents a selection of items potentially relevant for a comprehensive examination-technique and it illustrates the difficulties and problems present in neurological and developmental assessment during infancy.

# Chapter II Design of the study

In a small and strictly selected but extensively documented group of low-risk infants, a large number of items of the neurological repertory was assessed longitudinally at four-weekly intervals.
Details on the selection-criteria of the sample will be given in chapter III, and on the examination-procedure in chapter V. The group consisted of 51 infants, 28 boys and 23 girls.

A decision had to be made concerning the length of the follow-up. Although it seemed attractive to use calendar-age as a cutting-point, the well-known inter-individual variations in functional development made this criterion less appropriate. Therefore it was decided upon to fix on a developmental milestone, namely the age of walking free for at least seven paces, as the limit of the follow-up. Consequently the size of the group decreased gradually after the chronological age of about one year.

### Prediction bands

A presentation of the actual percentages of the group could be considered as misleading, as a greater and more general significance would be attached to such data than is justified. Therefore, it was decided to present 80% prediction bands, which show all the possible scores obtained by at least 80% of the infants at the consecutive assessments.
Beside the 80% prediction band, the full range of scores, i.e. scores obtained by 100% of the infants, will be given. The prediction bands illustrate the general developmental course of the items and the inter-individual overlap of scores occurring at comparable ages. The cutting-point of 80% was chosen arbitrarily. For the relatively small group of infants examined, this limit gave scope for sufficient differentiation. At the same time the effect of extremely fast or slow development, as occurring in some infants, on the variation of scores was minimalized. As for these infants, a complete variation range of the scores (i.e. 100% prediction bands) is added.
It should be stressed that a 80% prediction band may not be identified with the band-width between the 10th and 90th centiles. The prediction bands mainly visualize the trend of the development. They present the scores which are obtained by the majority of the infants at consecutive ages. The position of the prediction band on the time-axis indicates the time course of the development, its length reflects the rate of development, and its width describes the number of scores which can be found in the group of infants at one comparable age.
Finally the shape of the prediction bands indicates the developmental course of the items, by showing the sequence in which indentifiable scores may be obtained consecutively during the period of development.

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am grateful to Prof. Dr. W. Molenaar for bringing to my attention the potential value of prediction bands.

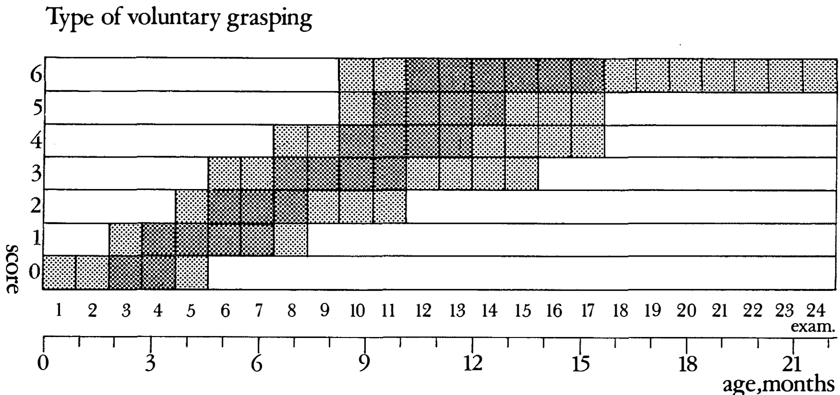


Fig. 1:

Type of voluntary grasping: example of prediction bands. Key for fig. 5-20, 23-44.
Vertical axis: scoring scale of the response.
Horizontal axis: number of follow-up examinations from the neonatal period onwards.
Below the horizontal axis the corresponding time scale in months is drawn up. The dark-shaded area represents the 80% predictionband for this item, i.e. the scores at particular examinations obtained by at least 80% of the infants. The light-shaded areas on each side of the dark-shaded one represent the scores obtained by the rest of the infants, so that the dark-shaded and light-shaded areas together represent the scores obtained by the total group of infants (i.e. 100%).

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As an example of a prediction band, in fig. 1 the development of the type of voluntary grasping is presented. The possible scores during the developmental course are given vertically, in this instance a seven point score (the exact meaning of these scores is given on page 54 in the paragraph on the development of this item).
On the horizontal axis the number of examinations is given; as the examinations took place once per four weeks, the number of examinations represent time graded in four-week intervals.
A time scale in months is drawn up so that one may calculate the infant's age. The dark-shaded area demonstrates the 80% prediction band, which means that at the examination in question at least 80% of the infants got the scores indicated by the dark shading. The light-shaded areas on both sides of the 80% prediction bands give the full range of scores obtained by the infants at each examination. For instance, at the 4th examination at least 80% of the infants obtained a score 0 or 1, as indicated by the dark shading. As is clear from the absence of light shading, other scores were not given, which implies that at this examination all infants obtained a score 0 or 1. Yet the number of infants obtaining a score 0 or a score 1, respectively, is not indicated. It is merely stated that at this examination, at the age of about four months, the infants may obtain a 0 or a 1, i.e. de not grasp voluntarily or have just started to do so. An analogous situation arises at the 12th examination, when all the infants were found to score 3, 4, 5 or 6. At the eighth

examination (age about $7\frac{1}{2}$ months) at least 80% of the infants scored 2 or 3, as is indicated by the dark-shaded area, while the rest of the infants may still score 1 or already score 4, as is indicated by the light-shaded area.
At the fifteenth examination (age about 14 months) at least 80% of the infants obtained a score 6, i.e. the final score as defined for this item in this study, while maximally 20% of the infants still scored 3, 4 or 5. Finally, at the 18th examination (age about 17 months) all infants were found to score 6.

A final remark must be made concerning the presentation of the prediction bands. As the infants in study were followed-up till they walked without any support, the size of the group depended on the developmental rate of this motor function. Consequently from the 12th examination onwards, i.e. after about 48 weeks, the total number of infants decreased steadily. The 80% prediction bands were calculated for the actual size of the group at the specific examination time, so that after one year of age the percentages were calculated for different numbers of infants. Consequently the shape of the bands at the end of the time scale is often rather irregular. Nevertheless it was decided not to normalize the percentages to the size of the original group (N = 51), as the response of the items obtained at the age of walking without support could not be said to be the final, stable response in all instances (in the case of e.g. the footsole response).
Moreover, the majority of the neurological items showed their developmental course within the first year of life, so that the prediction bands are localized on the time scale mainly in the period in which the size of the group had hardly changed. The actual number of infants examined is given in figure 3.

**Interrelationships**

As will be reported later the items could be divided into four categories; the criteria were: the differentiation among the infants, and the possibility of defining an evident developmental sequence during infancy. An evident developmental sequence was taken to be present if the first developmental change and the final change (i.e. stabilization) of the response during the period of study could be defined unequivocally.
Stabilization means either the definite disappearance of a response, such as the palmar grasp reflex, or the presence of a so-called "mature" response such as for instance walking without help in the case of locomotion as the end of the developmental course.

A fifth category was added which comprised a few items such as body length, skull circumference, smiling and speaking, which could not be included in any of the other categories.

For the items which differentiated sufficiently among the infants and which showed a well defined developmental sequence, four parameters were established:

a. the age of the first change of the response
b. the age of the final change of the response
c. the length of the developmental course, i.e. the amount of time between first and final change, measured as the number of four-week intervals.
d. the number of inconsistencies occurring during the developmental course of the item. Inconsistencies were defined as temporary relapses into a former developmental phase, reflected by scores appropriate to a younger age.

For the analysis of the development of neurological phenomena during infancy, these parameters were chosen because they characterize each single item in terms of early versus late development, fast or slow development and consistency of development. They enable the examiner to determine whether an early or late first change leads to an early or late stabilization of a response or reaction, which means that the time needed for the development is fairly constant, or whether, irrespective of the moment of the first developmental change, the moment of final stabilization is more or less fixed in time.
It is also possible to determine a possible relation between the length of time needed for the development of an item (expressed in the developmental range) and the occurrence of inconsistencies during development (see further chapter XIII).

Categorization of the items according to comparable interrelationships between their parameters and interpretation of these interrelationships may serve to increase insight into the dynamics of neurological development. Beside an analysis of the interrelationships between the four parameters of each single item, the interrelationships between parameters of different items were analysed in order to explore the existence of a coherent frame in which the maturation of the central nervous system and the functional motor development fits.
For this analysis only the items with an evident developmental sequence were used and the intercorrelations of each of the four parameters were calculated. In this way we tried to find and define clusters of items which were comparable with respect to time of onset and end of development, rate of development and consistency of development. Such clusters, if present, may yield information about the programming of the brain during development.

# Chapter III The criteria for selection

The criteria for selection of the infants were:

I. *Low-risk pregnancy and delivery*

Extensive information about pregnancy and delivery was obtained from the mother, and if necessary this information was checked with the doctor or midwife who attended her. The information was recorded on a precoded form. The obstetrical data, obtained from the mother (naturally data about the condition of the placenta for instance could only rarely be gained) were checked with the optimality ranges as defined by Prechtl (1968). An obstetrical optimality-score was then calculated by counting the number of optimal obstetrical conditions. This method of evaluation of the obstetrical history makes it possible to quantify the course of pregnancy and delivery.

As Prechtl (1968) has pointed out, it is difficult to define the weight of obstetrical complications. It is much easier to define an optimal range, i.e. the quality of obstetrical conditions which refutes any doubt about their integrity.

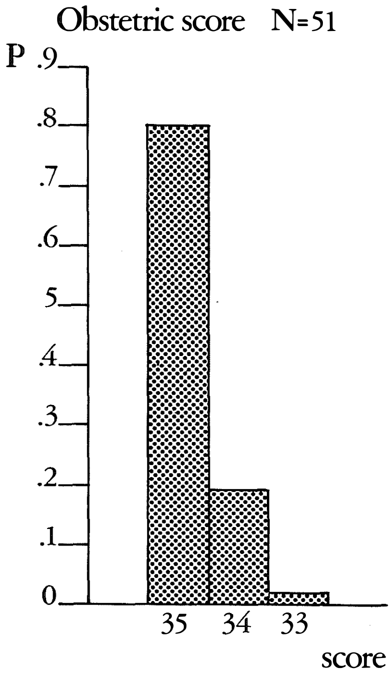



Fig. 2:

The precentage distribution of the obstetrical optimality scores.
Vertical axis: number of infants expressed as the percentage of the total group (N = 51).
Horizontal axis: number of optimal obstetrical conditions.

Moreover, Prechtl could show that non-optimal conditions, i.e. obstetrical conditions outside the optimal range, which have clinical significance only rarely occur as isolated phenomena. In the present study, in which cases of major or overt obstetrical complications were excluded beforehand, the obstetrical optimality-score enabled us to scrutinize the obstetrical history of the infants. In appendix A the optimality rages, as defined by Prechtl (1968), are given.

Fig. 2 shows the percentage distribution of the obstetrical optimality-scores of the group. As can be seen, all the infants belong to an obstetrical low-risk group.

II. *The low-risk neonatal neurological examination*

The neonatal neurological examination was carried out according to the method described by Prechtl and Beintema (1964). The neurological findings were compared with the criteria given by these authors. On the basis of these criteria an optimal range was defined for the responses of the examination. By counting the number of optimal conditions, i.e. findings within the optimal range, a neurological optimality-score was determined.

Appendix B shows the criteria for neonatal neurological optimality. All 51 infants met these criteria. Thus the infants of the study can be considered as not only belonging to an obstetrical low-risk group but also to a neurologically optimal group with respect to the neonatal examination.

III. All the infants were selected from a homogeneous socio-economic class, in order to eliminate variances in development due to this issue as much as possible. It is generally understood that socio-economic class does not affect the rate of development in infancy, at least in Caucasian populations, while it does affect development after infancy. (Hindley, 1960, 1961; Bayley, 1965; Francis-Williams and Yule, 1967). Still discussions on this subject continue (see for instance Knobloch and Pasamanick, 1963). Neligan and Prudham (1969) in their longitudinal population study in Newcastle upon Tyne found that there was a significant relationship between socio-economic class and the milestone of walking without support.

**TABLE II**

**Occupation or vocational training of the fathers**

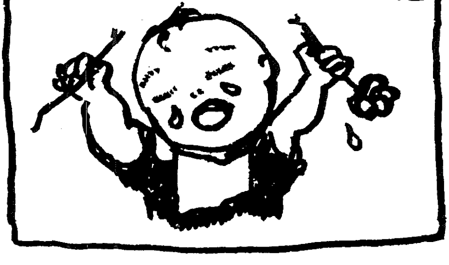
| | |
|---|---|
| Academic training: doctors, chemists, physicists, etc. | 36 |
| Higher occupational training: architects, accountants, etc. | 5 |
| Managers and business people | 4 |
| Chief-agents | 2 |
| Public servants | 2 |
| Technicians | 2 |
| | 51 |

In view of these findings it seemed advisable to keep the parameter of socio-economic class constant. The socio-economic class chosen was the upper-middle class, determined by the father's occupation (Table II). In this class repeated assessments could be carried out without too much difficulty and in Holland feeding- and caretaking attitudes could be expected to be rather homogeneous in this socio-economic class.

IV. It was necessary that the number of boys and girls was nearly equal. There are only few data available about the existence of differences of developmental rate during infancy between boys and girls.
In general these data point to a higher vulnerability of boys compared with girls to different kinds of adverse conditions, which may be reflected in the developmental course. According to Zachau-Christiansen (1972), in normal infants born at term the differences in motor development are very small at the age of one year. Neligan and Prudham (1969) reported differences for speech development only. Smith's data, reanalysed by Hindley (1967) suggested that girls walked significantly earlier than boys; these data were mainly based on non-caucasean populations. Neither Bayley (1965), nor Hindley et al. (1966), nor Francis-Williams and Yule (1967) found substantial sex-differences between boys and girls during their development.
In the present study all the items of the examination were checked on possible differences in development due to sex, before the developmental course was analysed in the total group. To serve this purpose care was taken that in the sample boys and girls were represented about equally.

V. The infants were not related to each other; all of them were Dutch natives, so that there are no cultural and racial influences on the development (see also Touwen, 1974).

VI. From a general pediatric point of view the infants were inconspicious at birth. In all the cases a medical examination was carried out by the family doctor in the first month after birth. Only if the results of this examination proved normal, was the infant kept in the group. None of the infants had to be excluded due to abnormal findings by the family doctor.



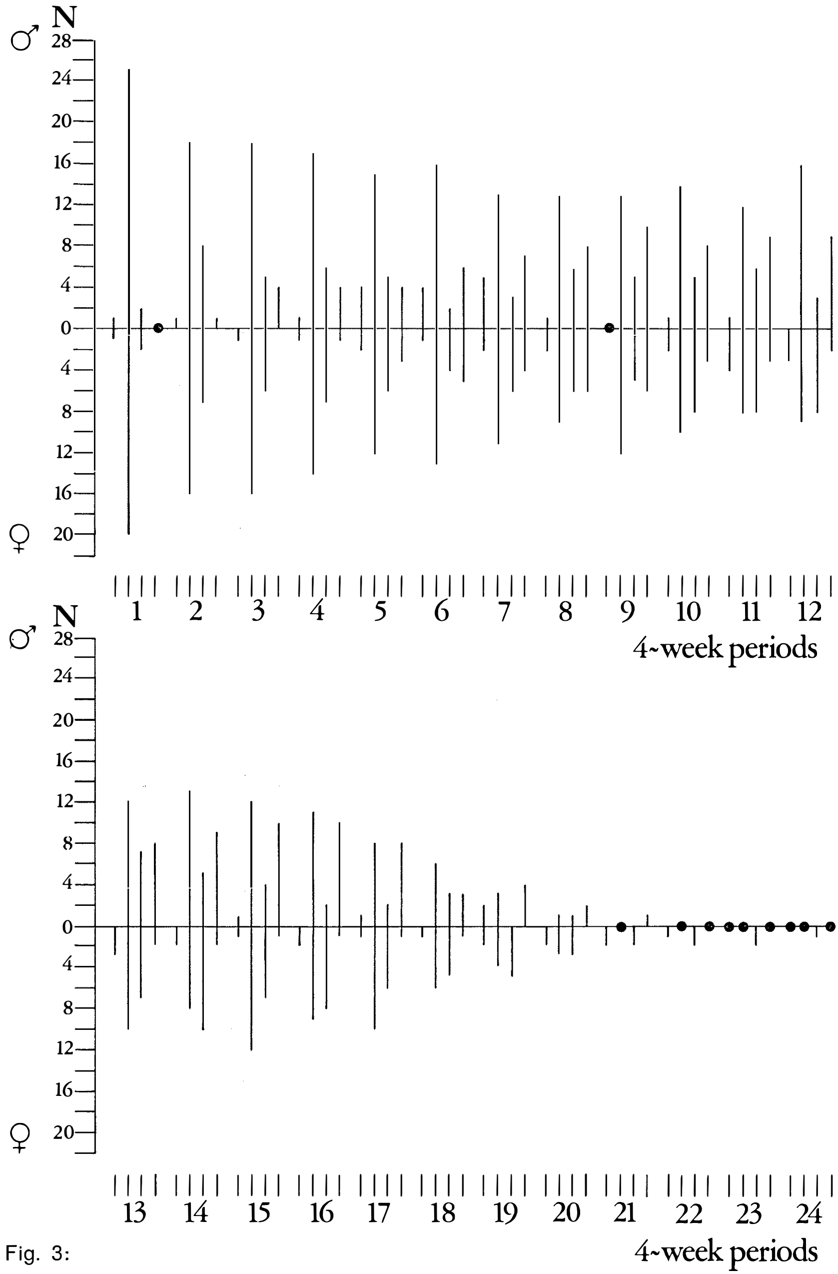



Fig. 3:

The frequency-distribution of the assessments during the consecutive four-week periods.
Vertical axis, upper part: number of the boys; lower part: number of the girls.
Horizontal axis: number of four-week periods, each of which is graded in four single weeks.
During each four-week period each infant was assessed once. Till the twelfth four-week period the total group consisted of 28 boys and 23 girls; from the twelfth four-week period onwards the number of boys and girls gradually decreased.

# Chapter IV The follow-up examination

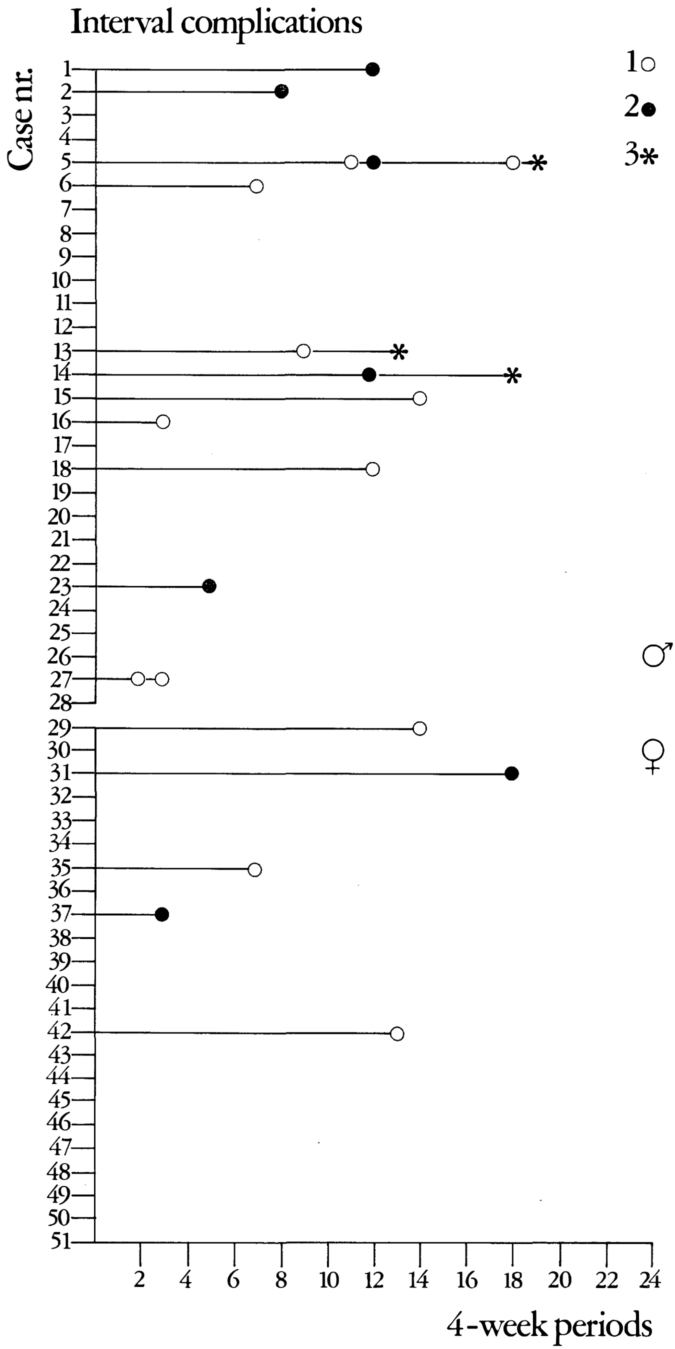
The infants were examined at home in their own environment with four-weekly intervals, in order to keep the environmental conditions intra-individually as constant as possible. The infants had ample time to adjust themselves to the examiner's presence. The mother was present during the examination.

It was not possible to examine all the infants at strict four week-intervals. In the majority of cases the interval between two consecutive examinations was four weeks, but sometimes the interval was three or five weeks. Nevertheless all children underwent an examination in a period of four weeks.
Fig. 3 shows the frequency distribution of the examinations during the consecutive four-week periods. It can be observed that boys and girls show a slightly different distribution. The majority of the girls was examined during the second and third week of the four-week period so that the distributions are unimodal. The histograms for the boys show two peaks from the sixth four-week period onwards: one at the second and one at the fourth week of the period. The boys belonging to the second peak group therefore may appear to show a somewhat faster development than the other boys and than the majority of the girls, due to the time of examination and the method of analysis, which was based on complete periods. This has to be kept in mind when the results with relation to sex are discussed.

In order to standardize the influence of endogenous variables such as fatigue and hunger, the infants were examined at a fixed time of the day, i.e. at around six o'clock in the evening before feeding.

Interval complications, i.e. disorders during the period of study, if present, were recorded and coded on a four point scale: 0: no illness or disorder; 1: slight disorders without fever or evident influence on the infant's behaviour, such as mild colds; 2. disorders accompanied by fever up to 39° centigrade, lasting for one day at most or accompanied by feeding disturbances resulting in vomiting and/or diarrhoea without weight loss; 3: serious illness with fever above 39° centigrade and/or lasting longer than one day, and/or feeding difficulties resulting in weight loss.

Convulsions would have scored 3, but did not occur. Fig. 4 represents the distribution of interval complications observed in the infants during the period of study.


Interval complications
Case nr.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
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41
42
43
44
45
46
47
48
49
50
51
2
4
6
8
10
12
14
16
18
20
22
24
4-week periods
1○
2●
3*
♂
♀

Of the total group of infants, 16 (about 1/3) showed 22 interval complications. This means that several of the infants showed an interval complication more than once. The majority of these interval complications consisted of very mild disorders, such as slight colds or mild reactions to vaccinations (variola, diphtheria, tetanus, whooping cough, poliomyelitis acuta anterior; the latter four, compounded in one injection, are given three times during the first year of life). Only 3 of the infants, all of them boys, suffered from more serious disorders. One boy had chickenpox with high fever during three days, accompanied by extensive skin eruptions, when he was one year of age. Another one was hospitalized for an asthmatic attack when he was 16 months. The third boy was hospitalized for a skin disease without fever when he was about 1½ year. None of these infants showed signs of regression in their neurological development after the disease. Although interval complications occurred more frequently among the boys than among the girls, this sex difference did not prove to be statistically significant (chi-square = 1,8).

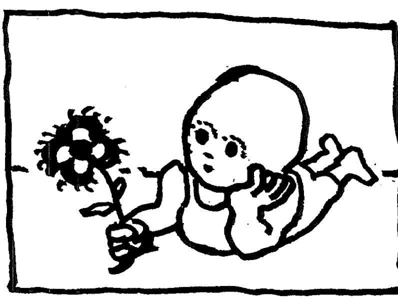


Fig. 4:

The distribution of the interval complications during the period of study. Vertical axis: case numbers; no's 1-28 are the boys, no's 29-51 are the girls of the group.
Horizontal axis: time scale graded in four-week periods. Circles: mild interval-complications; dots: interval complications of moderate intensity; stars: serious interval complications.

# Chapter V A short description of the course of the examination

At each session the complete set of items was assessed. The neonatal examination was carried out according to the method described by Prechtl and Beintema (1964). Its results served as one of the criteria for the selection of the group, as discussed in Chapter III. For the follow-up examinations, however, a method had to be developed in which the expanding repertory of the infantile nervous system during development was taken into account. Consequently the number of items to be assessed increased, but the strategy remained unchanged, also with respect to the sequence of the tests. A pilot study of ten infants, which were omitted from the analysis subsequently, served to develop an examination technique which will be described in this chapter.

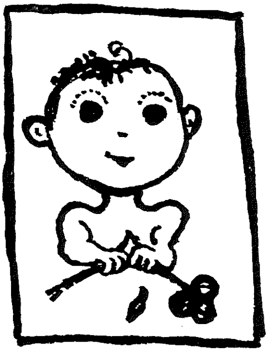
Standardization of the behavioural state during the examination, which is of extreme importance for the interpretation of the results (Prechtl and Beintema, 1964; Prechtl, 1972) was applied rigorously.
All the infants were assessed in the optimal cooperative behavioural state, i.e. relaxed or moderately active. As soon as an infant started to cry the assessment was put off until the infant was happy and relaxed again. If necessary the examination was postponed to another day.

The examination always started with an adaption period during which observation of spontaneous and goal-directed motor behaviour was carried out. The duration of the adaption period depended largely on the age of the infant but the observation lasted at least three minutes.
During the first 5-6 months most infants were observed in their cribs, afterwards mainly in the playpen. After the observation, the infant was put on the dressing table or on its mother's lap, dependent on its age. Voluntary grasping was then tested by means of an ovoid plastic object (two by three by three cm) presented in the midline. With increasing age the number of objects presented was augmented. During the presentation of the object, facial innervation and the visual system were examined. A small baby-bell was used to assess hearing and acoustical orienting. Then the quality of the motor apparatus was tested, i.e. the resistance to passive movements, active power, and the range of movements, followed by the evaluation of responses and reactions such as the tendon reflexes of arms and legs, plantar grasp, footsole response, palmar grasp etc. During the examination of the motor apparatus of trunk and neck the presence of the asymmetric tonic neck reaction was assessed. Sitting behaviour, and spontaneous motility and posture of head, trunk, arms and legs during sitting were evaluated. Depending on the age of the infant, standing and walking were assessed. Then the examiner kept the infant in vertical suspension and observed the posture and motility of the legs. Placing reactions of the legs and, in young

infants, automatic stepping movements and positive supporting reactions were tested. After the evaluation of the rotation test the infant was kept in horizontal suspension and the Landau and Schaltenbrandt reactions were assessed.
Subsequently the infant was put in prone position on the dressingtable or on the floor, and the motility of head, arms and legs, the quality of locomotion in prone and rolling behaviour were evaluated. Thereupon the Moro reactions were tested and the session ended with the evaluation of rooting and sucking behaviour and of those responses for which the infant must be undressed, such as the abdominal skin reflex, the cremasteric reflex and the Galant response.
Length and weight of the body were measured, as well as the skull circumference (fronto-occipital measurement). Vocalization or speech was recorded as observed during the whole course of the assessment, and information about speech was asked from the mother.

Evidently the number of items enlarged in accordance with the increasing neurological repertory of the infants. Still it was possible to adhere to the general course of the procedure as described above. The duration of the assessment, the adaption period included, increased specifically in infants older than seven or eight months of age. At that age the majority of the infants often developed rather strong withdrawal reactions, which frequently resulted in an expansion of the adaption period, sometimes to more than three quarters of an hour.

The results were recorded on a precoded form during the assessment. Information given by the mother was recorded also, but for the assessment of functional development only directly observed phenomena were used.



# Chapter VI The presentation of the results

The items of the assessment could be divided into five groups according to their characteristics during development:

Group I
A group of items which did not show differentiation among the infants and which did not show any changes occurring during the period of study, such as the resistance against passive movements, pupillary reactions and reaction to sound (Table III).

Group II
A group of items which showed little differentiation among the infants, and/or showed a very rapid developmental course, such as spontaneous tremor, corneal reflex, stepping movements and conjugation of eye movements (Table IV).

Group III
A group of items which showed fair differentiation between the infants and which presented a definite developmental course, of which a first change of the response and a final change (stable, so-called mature response, or disappearance of the response in the case of "infantile reactions") could be defined. Examples are items describing the development of sitting, standing, walking, crawling etc., the footsole response, the palmar grasp reflex, the Moro reactions and the optical placing reactions (Table V).

Group IV
A group of items which did not show differentiation among the infants but, interindividually as well as intraindividually, showed so many inconsistent changes that a definite developmental sequence could not be established. In this group also those items are included which did not reach their final change within the period of the follow-up study. Examples are the spontaneous posture of head and trunk during prone suspension, the Landau and the Schaltenbrandt reaction, the knee jerk, and the plantar grasp reflex (Table VII).
The changes occurring in the items during the follow-up period will be described, but they are not used for the analysis of interrelationships, as comparable parameters with group III were not available.

Finally there is a group of variables which deal with the infants from an anthropometric and pediatric point of view, such as body weight, length, skullcircumference (Table VIII); also variables which may be regarded as having psychosocial significance such as vocalization, smiling and reaction towards strangers, i.e. which cannot be considered as purely neurological items (Table IX).

The groups of items will be discussed in the following chapters. For reasons of convenience the items are subdivided into two groups: one consisting of items which can be observed without specific manipulations being necessary ("spontaneous posture and motility"), the other consisting of "reactions and responses", i.e. items for which manipulation of the infant was needed. The developmental course of the single items will be reported, and 80% prediction bands are presented if the developmental range and the differentiating capacity of the examination method made this worthwhile. Attention will be paid to the occurrence of inconsistencies, and also sex differences will be dealt with.

For the items of group III (i.e. items for which first change, final change, developmental range and number of inconsistencies could clearly be defined) the means, standard deviations and coefficients of skewness and kurtosis of these parameters are presented in appendix C. As it may be assumed that the distributions of the moments of first and final change, and also of the length of the developmental ranges are sufficiently symmetrical (cf. chapter XIII), the measures presented in Appendix C can be used to describe the parameters.
The Pearson Product Moment correlation technique was used for the computation of relationships between the moments of first and final change and the developmental ranges (i.e. the length of the period between first and final change) to be observed in single items as well as between different items.
This was not done when the frequency distribution of scores was not fairly symmetrical, as was often the case with the number of inconsistencies. Then Spearman Rank Correlation Coefficients were computed.

When the developmental course of the items is described, the interrelationships occurring in the single items or with other items will be reported. The correlation-coefficients of correlations with $p \leqq 0{,}01$ are summarized in appendices. Appendix D summarizes the correlation-coefficients of the relationships between "first change" and "final change" of items; appendix E presents the correlation-coefficients of the interrelationships of "first changes", appendix F and G present the correlation-coefficients of the "final changes" and "developmental ranges" respectively.
In the discussion of the items attention will be paid to relevant data obtained by other authors. An extensive discussion of the literature available is not presented in the case of all the items, as the present study does not pretend to be a comprehensive survey of the literature about infantile development.

# Chapter VII Group I: Items which did not show differentiation among the infants

In this chapter the items will be discussed which remained constant throughout the whole follow-up period (Table III).

**TABLE III**

**Items which did not show differentiation among the infants (group I)**

Facial innervation
Pupils — shape
— reaction to light
Optical blink
Acoustical blink
Reaction to sound
Muscle tone — resistance against passive movements
— active power
— range of movements
Head control
Abdominal skinreflex
Cremasteric reflex
Withdrawal reaction

### Facial innervation

All infants showed a symmetrical facial musculature from birth onwards. Facial expressivity increased after the first weeks, but a standardized description was not endeavoured.

### Pupils

In all the infants the shape of the pupils was round; this did not change during the period of study. In all the instances the direct and indirect reactions to light were positive and did not change.

### Optical blink

This response was elicited according to Prechtl and Beintema (1964). In all the infants it was present and did not change, provided that the light stimulus was of sufficient intensity.

### Acoustical blink

Elicitation according to Prechtl and Beintema (1964). In the newborn period all the infants had a positive acoustical blink to hand clap. Provided they were examined in a quiet environment, the response remained positive during the whole period of study.

**Reaction to sound**
For this response a small baby bell was used. All the baby's reactions, for instance changes in motility, changes in facial expression, gazing or blinking, were considered as a positive reaction. All the infants showed a positive response from the newborn period onwards. This is in accordance with the report of Chun, et al. (1960); still their opinion that the acoustical blink was hardly ever found after the age of 5 months could not be confirmed.

**Muscle tone**
Three aspects were assessed according to the technique described by Prechtl and Beintema (1964): resistance against passive movements, active power, range of movements.

*The resistance against passive movements* was assessed exclusively in state 3 (for the operational definition of states see Prechtl and Beintema (1964)).
In state 3 the infant is awake, completely relaxed, and not actively moving. When there was no noticeable myotatic reflex-activity resistance against passive movements was comparable for flexor and extensor muscles and did not differentiate among infants nor were evident changes of its quality found at the consecutive examinations.
As the infants were awake during the assessment, the handling of their arms and legs did not fail to activate them, so that in many cases state 3 was not maintained.
During activity the resistance in the flexor muscles of arms and legs was found to be higher than the resistance in the extensor muscles. This difference between flexors and extensors increased during the first two or three months; it seemed largely due to resistance against active movements.
With the technique used it was impossible to quantify differences between resistance against passive and against active movements. In the present group no evident differences were found between the consecutive assessments which could be attributed to properties of muscle tension in state 3. An evident decrease of resistance at older ages seemed to reflect the infants' capability of voluntary relaxation during state 4. No evidence was found for the often reported, so-called "physiological" flexor hypertonia of early infancy (André-Thomas and St. Anne Dargassies, 1952) or "elastic hypertonia" (Willemse, 1973), as long as the behavioural state of the infants was duly controlled. It should also be kept in mind that traditionally the term "hypertonia" implies a pathological condition and consequently cannot be applied in normal infants.

The resistance against active movements, which reflects *active muscle power,* increased with age but could not adequately be operationalised, due to the rapidly increasing differentiation of muscle activity and muscle tissue during infancy. Evident decrease or lack of active muscle power was not found in any of the infants.

Presumably the difference between flexor and extensor muscle-activity during the first months of life reflects a dominance of the neural mechanisms for flexor muscle-activity as well as the difference in bulk of the flexors and extensors.

The *range of movements* of the joints showed a certain degree of variation, intra- as well as inter-individually; however, this seemed to depend largely on the individual characteristicts of the baby.
During the pilot study measurements of angles between joints were carried out but the results appeared to be inconsistent at consecutive assessments, so that they were discontinued. The arousing effect of such measurements may have been largely responsible for these inconsistencies. Consistent changes in the range of movements were not found.

**Headcontrol**
Headcontrol in sitting position was examined according to Prechtl and Beintema (1964). In the newborn period all the infants were able to balance their heads for more than 3 seconds and thus obtained an optimal score. This could be observed during all the consecutive examinations. Adequate head control during sitting position can be considered as evidence for a good interplay of afferent vestibular and neck-proprioceptive and efferent muscle power activities. The amount of slight swaying movements which accompanied the maintenance of the head balance during the first months, was not appreciated.

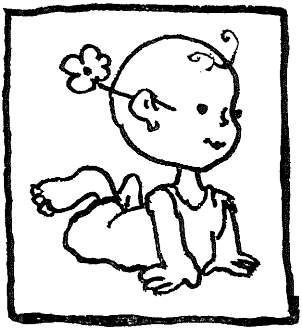
**The abdominal skin reflex**
This reflex was present from birth onwards. However, the chances of a proper elicitation varied in the newborn period and at subsequent ages. In newborns elicitation of the reflex was easiest in state 3. When the infant became active it was often difficult to elicit the response. From the second examination onwards also in moderately active infants the response could easily be elicited. The finding of Harlem and Lönnum (1957) that in newborns the response is more extensive than in adults was confirmed. This was also the case in older infants. The meaning of this phenomenon is not clear. On the one hand the infant's smaller volume allows for an increased effect of muscle contractions, on the other hand there is such variability in abdominal skin responses in adults as to make conclusions unreliable. Moreover, the infant in general appears to be more "ticklish" than the adult.

**The cremasteric reflex**
All the boys had a well developed scrotum and descended testicles at birth. In all of them the cremasteric reflex turned out to be present from birth onwards.

**The withdrawal reaction**
All the infants reacted to a gentle pinprick on the footsole with a vigorous withdrawal reaction of the foot and leg. This reaction did not show any changes from birth to walking free.

**Comment**

It was found that the items of this group did not show any substantial changes throughout the developmental period as defined in this study. This implies that their neural mechanisms are fully established at least at birth. From a developmental point of view these neural mechanisms can be said to be of primary importance. They form the basis on which further functional development relies. The nervous system must be able to generate adequate muscle tension in order to make all kinds of motor behaviour possible. Similarly mechanisms for visual and acoustical mediation are a prerequisite for the development of differentiated visual and acoustical functions, such as for instance visuomotor abilities or adequate localisation of the sources of sounds. Theoretically it can be argued that an impairment of these mechanisms destroys or largely hampers the possibility of adequate functional development. Consequently it is evident that these items are of great significance for a neurological diagnostic procedure. Moreover, if the neural mechanisms underlying these items are of such basic value for the functional development, it may be assumed that in cases of disturbances resulting from impairment of these mechanisms proper treatment will be rather difficult.



# Chapter VIII Group II: Items which showed little differentiation and/or a rapid developmental course

In this chapter those items will be discussed which showed a very rapid developmental course and displayed hardly any interindividual differences. In the present study with four-weekly examinations an item was estimated to show a rapid developmental course if it lasted for a period of only 3-4 four-week intervals in more than 80% of the infants.
More accurate information about the developmental course of these items would require longitudinal examinations at shorter intervals. With the inter-examination-intervals of four weeks appreciable gradients of score, which would show differentiation between the infants could not be detected. The items belonging to group II are presented in Table IV.

**TABLE IV**

**Items which showed little differentiation and/or rapid developmental course (group II)**

Spontaneous tremor
Tremor during Moro-reactions
Conjugated eye movements
Fixation time
Visual pursuit movements
Convergence of the eyes
Pupillary reaction to convergence
Corneal reflex
Doll's eye phenomenon
Rotation test
Lip-tap reflex
Recoil of the elbow
Biceps reflex
Ankle jerk
Stepping movements

### Spontaneous tremor

At the newborn examination ten infants showed a slight tremor of high frequency ($\geqq$ 6/sec) and low amplitude ($\leqq$ 3 cm) during spontaneous activity. The tremor was seen in their upper limbs only. Eight of them were boys and two were girls. Yet from the second examination onwards no tremor was observed any more, except in one boy who consistently showed a slight tremor up to about one year. Tremors of low frequency and high amplitude did not occur in the present group (cf. criteria for neonatal neurological optimality).

**Tremor during Moro-reactions**

As will be reported in chapter IX the Moro reaction was elicited in 3 different ways: by the head drop, the lift and the hit on the surface respectively. In the newborn period six infants (5 boys and 1 girl) showed a slight tremor of high frequency ($\geqq$ 6 sec.) and small amplitude ($\leqq$ 3 cm) in the head-drop Moro. These six infants also displayed a tremor during spontaneous actvity. At the second and third examination only one boy still showed a slight tremor which disappeared at subsequent examinations.

During the Moro reaction elicited by the lift-method, nine infants (4 boys and 5 girls) showed a high frequency and low amplitude tremor during the newborn examination. This number of infants decreased rapidly during the subsequent examinations, although one boy persisted in showing a slight tremor until the fifth assessment. This was the same boy who showed a tremor during the headdrop Moro at the second and the third assessment.

During the Moro reaction elicited by a hit on the surface twelve infants showed a tremor of high frequency and low amplitude during the newborn examination (5 boys, 7 girls). At the second examination only three infants (all of them boys) showed a slight tremor and from the fourth examination onwards no tremor was found.

During the lift Moro and hit Moro more girls than boys showed a tremor, but the few infants who persisted in having a tremor during the first few follow-up examinations were all of them boys. Yet the number of infants with a tremor is too small to allow for pertinent conclusions or even hypotheses. Other types of tremor were not observed.

**The eyes**

The development of an efficient visual apparatus showed a rapid developmental course during the first months of life in more than 80% of the infants.

a. *Conjugation of* eye *movements* was evaluated during the whole course of the assessment. For recording a four point scale was used:
   0. non-conjugated eye movements.
   1. occasionally conjugated eye movements.
   2. nearly continually conjugated eye movements.
   3. continually conjugated eye movements.

   During the newborn examination none of the infants obtained score 0; 16% of them obtained score 1 and 80% score 2. In these infants squinting occurred mainly during tests which required muscular exertion such as the traction-test and head-balance during sitting. Only 4% showed continually conjugated eye movements (score 3). At the second examination, i.e. at about the fifth week of life, one third of the infants showed continually conjugated eye movements. At the third examination this was the case with two thirds of the infants, while from the fifth examination onwards, i.e. from about 20 weeks of age, all the infants showed consistently conjugated eye movements. Boys were significantly later than girls in showing nearly continually conjugated eye movements (Mann-Whitney U test, $p = 0.01$), but the difference between the means of boys and girls was slight (see Table XI and XIII and chapter XII). This difference had disappeared at the time of onset of continually conjugated eye movements. The present findings are in agreement with Koupernik and Dailly's view that complete synergism between the eyes is established between 3 and 5 months of age (Koupernik and Dailly, 1968).

b. *Fixation time*

In order to assess the fixation-time the examiner kept a glittering silvery object of 3 by 4 cm in front of the infant's eyes and tried out at which distance the infant gave the best response.

The object was kept in movement in order to intensify the stimulation. The response was scored on a 4 point scale.

0. no fixation.
1. fixation during a few seconds only.
2. fixation during 15 to 20 seconds.
3. fixation during more than 20 seconds.

The test was carried out for the first time during the second examination. All the infants except two showed fixation during a few seconds at least, while 20% fixated longer than 20 seconds. At the third examination two thirds of the infants showed fixation during more than 20 seconds; about one third fixated during 15-20 seconds and only two infants fixated during a shorter time. From the fourth examination onwards, i.e. about 16 weeks, more than 90% of the children fixated longer than 20 seconds. The boys started to fixate slightly earlier than the girls (Mann-Whitney U test, $p. < 0.01$) but boys and girls reached a fixation period of more than 20 seconds at about the same time.

There was a low but significant correlation between the final stabilization of fixation and the onset of pursuit movements of the eyes as defined in this study ($r = .397$ $p < 0.01$).

Fixation depends largely on the quality of the stimulus. Therefore it is hardly feasible to compare the present findings with those of other authors who often do not describe the quality of their stimulation.

c. *Visual pursuit movements*

The object used in the test for fixation was also made use of in this test. It was moved in front of the infant from one side to the other, at the distance at which the infant fixated best.

The angle over which the infant followed the object with the eyes and head was estimated and scored on a 5-point-scale.

0. no pursuit movements.
1. pursuit movements over 30 degrees.
2. pursuit movements over 45 degrees.
3. pursuit movements over 60 degrees.
4. pursuit movements over 90 degrees or more.

The test was carried out from the second examination onwards.

Visual pursuit movements

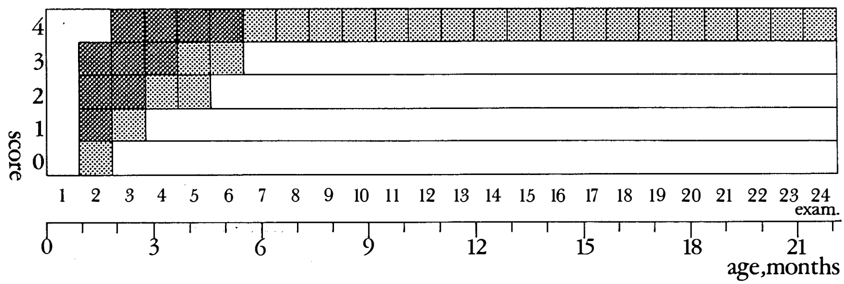



Fig. 5

Figure 5 shows the 80% prediction band and the full range of the responses. From the fifth examination onwards more than 80% of the children showed pursuit movements over more than 90 degrees. No consistent difference between boys and girls was found. Wolff (1965) reported visual pursuit movements in newborns. In the present study pursuit movements were looked for from the second assessment onwards; at that time at least 80% of the infants showed visual following over 30-60 degrees. It is possible that some of these infants would have shown visual following in their newborn period. The finding of Barten and Ronch (1971) that there is no relationship between neonatal visual pursuit movements and visual following at later ages, suggests that various mechanisms may be at work.

d. *Convergence of the eyes*

The same silvery object was now moved towards the infant's face from a distance of about 60 cm. A 3-point scale was used for scoring.

0. no change of eye position on approach of the object.
1. slight convergence of the eyes which soon disappeared.
2. evident convergence of the eyes which was maintained for a few seconds.

The test was carried out for the first time during the second examination. 75% of the infants showed a negative response while only 6% showed evident convergence. From the fifth examination onwards, i.e. from about 20 weeks of age, more than 80% of the infants showed evident convergence. Inconsistencies were observed in eleven infants, but none of the infants showed more than one relapse in score.

Boys turned out to be significantly later than girls in the acquisition of this visual motor activity (Mann-Whitney U test, $p < 0.01$). Still the difference of the means in the case of boys and girls was small (Table XI, XIII). Convergence of the eyes may be regarded as a manifestation of developing binocular vision. The present findings are in agreement with Koupernik and Dailly's report (1968) which says that there should be convergence of the eyes from the end of the third month onwards. They also confirm White's findings (1970) that visual accomodation to an approaching target is developed between the second and fourth month of life.

e. *Pupillary reaction to convergence*

During convergence the size of the pupils was inspected and the presence or absence of miosis of the pupils was recorded which can be considered to reflect development of accomodation. Although at the second examination 10% of the infants showed evident miosis, only at the age of 20 weeks i.e. at the fifth examination, was miosis observed in more than 80% of the infants. Hardly any inconsistencies were found, but there was a similar difference between boys and girls as was found in the case of convergence, (Mann-Whitney U test, $p < 0.01$).

A significant relationship between the development of convergence and pupillary reaction to convergence ($r = .588$) could be ascertained.

**Corneal reflex**

This reflex, elicited by lightly touching the cornea with a piece of cotton wool, was positive from birth onwards. During the newborn examination in all the infants, the reaction was slow, compared with the immediate and quick reactions occurring from the second examination onwards.

**Doll's eye-phenomenon**

This test was elicited by axial rotation of the infant when kept in supine suspension. At the newborn examination 84% of the infants showed a positive response; i.e. evident active eye movements contrary to the direction of the axial rotation. At the second examination the response was negative in 25% of the infants, i.e. partial eye movements or even an absence of eye movements contrary to the direction of the rotation. In 59% the response was dubious. From the third examination onwards more than 80% of the infants showed a negative response. No difference between boys and girls was found. The Doll's eye-phenomenon is a vestibular reaction. One might expect the development of fixation to interfere with the result of the testing-procedure, and it might be argued that the phenomenon would not disappear if no fixation-targets were available. As it was impossible to exclude fixation-targets completely, conclusive evidence on this issue could not be obtained. The infants could gaze into one direction or another unsystematically which apparently was sufficient to interfere with the response. Incidental observations showed that in drowsy infants of different ages a Doll's eye-phenomenon could still be obtained. Although these observations were not carried out systematically, it may be assumed that the Doll's eye-phenomenon does not disappear during development, but becomes latent due to the interfering effect of scanning movements of the eyes during wakefulness.

### Rotation test

During the rotation test, elicited according to Prechtl and Beintema (1964), in 96% of the infants nystagmoid movements of the eyes were found at the newborn examination. From the second examination onwards they were found in 100% of the infants, without the direction of the rotation being of any consequence.
It was not clear whether the nystagmoid movements were of optokinetic or of vestibular origin. There were many gross contrasts between dark and light (windows, shadows, large paintings of the walls etc.) in the background against which the infants were rotated. These supplied sufficient fixation targets for the infants, which are a prerequisite for the optokinetic nystagmus. On the other hand it was often found that a very slight turning movement, for instance over an arc of about 45°, was sufficient to provoke nystagmoid movements with a clearly distiguishable fast and slow component; this might point to a vestibular origin. During this proces of slight rotation acceleration is the main stimulus while presumably the contrasts in the visual field play a minor rôle. When rotation was continued, there seemed to be a decrease of nystagmoid movements in some infants, which points to a vestibular origin, while in others the frequency of these movements seemed to remain unchanged, which suggests an optokinetic origin. It must be concluded that on the basis of the present findings no clear distinction can be made between optokinetic and vestibular origin. Nevertheless it is evident that in his newborn period the infant is already able to make consecutive slow and fast consensual eye movements in a neatly coordinated way.

### Lip-tap response

The response, elicited by a brisk tap on the upper or lower lip, was scored on a four point scale (state 3).

0: negative response.
1: a phasic contraction of the orbicularis oris muscle.
2: a shortlasting tonic protrusion of the lips.
3: an evident tonic protrusion of the lips, often followed by smacking movements.

At the newborn examination all the infants showed a tonic response; in 96% of the cases this was scored as an evident tonic protrusion of the lips. At the second examination a tonic response was present in about two thirds of the cases, half of which scored 4, but in 20% of the infants no response was obtained.
At the third examination (age about 12 weeks) 10% of the infants still showed an evident tonic protrusion of the lips, but the number of negative responses increased (35%) and one fourth of the infants showed a phasic contraction as a sole response.
At the fourth and fifth assessments a minority of infants (about 15%) still showed a shortlasting tonic lip-protrusion, while in a rapidly decreasing number of infants a phasic reaction persisted until the age of

about six months. Two infants obtained the score 2 until the tenth examination. Inconsistencies occurred in 17 infants, usually once. An appreciable difference in inconsistencies between boys and girls was not found. Still the developmental course lasted significantly longer in the case of the girls (Mann-Whitney U test, $p < 0.01$), although the difference between girls and boys was very small (about the length of one interval) and less than one standard deviation from the means (Table X and XII).

**Recoil of the elbow**

At the neonatal examination all the infants showed a brisk flexion of both elbows when the two forearms were passively extended and then released. At the second examination half of the infants did not show a flexion at the elbows. The percentage of negative responses increased to 82 and 96 at the third and fourth examination respectively. There was no difference between boys and girls. It can be concluded that the active postural flexor dominance which is characteristic for the newborn period (André-Thomas and St. Anne Dargassies, 1952; Ingram, 1959; Prechtl and Beintema, 1964) decreases rapidly during the first two months of life.

**Biceps reflex**

The biceps reflex was elicited by tapping with one index finger on the other one which was placed on the tendon of the biceps muscle of the infants' semiflexed arm. There was a brisk response in the majority of infants at all the examinations. During the second examination two thirds of the infants showed an exaggerated contraction of the biceps muscle. During the third examination this still happened in about one third of the infants. Inconsistently the number of infants in which this exaggerated contraction was found (6, 4, 2 infants respectively) decreased rapidly. The infants who showed exaggerated reponses during several assessments were not identical, as inspection of the individual scores made clear; thus a conspicuous number of intra-individual inconsistencies occurred in the intensity of the response, especially during the first months. There was no difference between boys and girls.

**Ankle jerk**

At the newborn examination the intensity of the ankle jerk, elicited according to Prechtl and Beintema (1964) was graded medium in all the infants. During the second and third examination six infants showed a relative increase of intensity of the ankle jerk. However, these were different infants. Therefore the validity of these single observations can be questioned. One boy showed an increased intensity of the ankle jerk up till the 10th examination, i.e. until the age of 40 weeks. This was not the boy who persistently showed a slight tremor during spontaneous motility as mentioned above.

### Stepping movements

During the neonatal examination stepping movements, elicited according to Prechtl and Beintema (1964) were clearly present in 94% of the infants; three infants (6%) showed a weak response. Four weeks later the response was absent in 59% of the infants, and at the third examination only 6% showed weak stepping movements, notwithstanding the reinforcement by passive extension of the head as described by MacKeith (1964). In two infants (4%) a weak response remained present during the fourth and fifth examination, i.e. until the age of about 20 weeks. There was no difference between boys and girls. MacKeith's finding that passive extension of the head results in a prolonged presence of stepping movements in a majority of infants, could not be confirmed. This might be due to the fact that the examiner started to apply the passive extension of the head only at eight weeks, when stepping movements without head extension were not present anymore.

Because of the very small number of infants who showed persisting stepping movements after the first assessment, a relationship between these movements and the onset of walking could not be ascertained. The infants who still showed the response at the third assessment did not walk remarkably early. Zelazo's suggestion that a persistence of stepping movements would result in an earlier onset of walking could therefore not be confirmed (Zelazo et al. 1972). However, the number of infants was too small to allow for definite conclusions on this issue.

### Comment

The items of this group can be divided into two subgroups. The first subgroup contains those items in which the majority of the infants behaved in a similar way. The items meant are: tremor during spontaneous motility and moro-reactions, the ankle jerk and the rotation test. As for the rotation test, its differentiation is very sligth and brief; the item shows a very rapid developmental course so that it can be ranged between group I (chapter VII) and group II. The other items of this subgroup (tremor and ankle jerk) scored qualitatively differently for a considerable period of time in a very small minority of the infants, in contrast with the large majority of the infants. Thus in one infant a spontaneous tremor was found up till the age of one year, while in the case of a few infants an increased intensity of the ankle jerk was observed during the first few months of life, in one infant even until the tenth examination. It is rather difficult to draw any conclusions on the basis of these single observations. Tremors of high frequency and low amplitude are well-known phenomena in neonatal neurology, especially in infants who are exhausted or upset. They may be seen as oscillations occurring during coordinated motility. As they mainly occur in times of stress on the nervous system (when the infants are exhausted, crying, hungry, upset etc.) they suggest that the brain organisation for this particular movement control is not yet consolidated and can easily be disturbed.

Clinically they are considered to be of little significance.

Tremors being present in some infants for a long period of time during development can be interpreted as an example of the variability in the maturation of the nervous control-systems underlying smooth movement.

The second subgroup of group II contains those items which show a fair differentiation among the infants, but at the same time have a rapid developmental course. Considering the frequency of assessments in the present study, their development can be said to figure as a stepfunction. These items seem to be based on neural mechanisms comparable to those of the items of group I which showed no changes during development. It may be argued that they reflect an increase of the scope and of the differentiation of these neural mechanisms. The disappearance of the recoil of the elbows, e.g., would reflect the decrease of the flexor dominance which is characteristic for the newborn baby. Its disappearance is indispensable for the functional development needed for adequate use of the arms. In a similar way the items concerning the eyes reflect a refinement and extension of the neural mechanisms indispensable for the development of an appropriate visual apparatus. The latter is a prerequisite for adequate further functional development, such as mechanisms which ensure conjugated eye-movements and fixation. The disappearance of stepping movements, which are based on a spinal coordinating mechanism, illustrates the domination of these movements by more complex mechanisms manifesting themselves in different motor patterns. This process finally results in the maturation of mechanisms for walking free. Theoretically it can be argued that the rapid developmental course of all items of this subgroup reflects the maturation of still rather basic neural mechanisms. Their impairment may easily result in a disturbed maturation of more complex neural mechanisms, the voluntary motor system included.
This stresses the significance of the items of group II for neurological diagnosis.

# Chapter IX Group III: Items which showed an evident developmental sequence

The items of this group fulfilled the following criteria:

1. The first change of the response could unequivocally be defined on the time-scale.
2. Also the final change could be defined accurately on the time-scale. The definition of first and final changes depended on the standardization and the operationalization of the scoring scale, which will be described in connection with every single item. A first change may be a qualitatively different response, as for instance with the type of voluntary grasping or spontaneous motor behaviour, or it may be a quantitatively different response, e.g. a decreasing intensity of the response, as is the case with the palmar grasp reflex. As for phenomena which manifest themselves in the course of the development, the first change was defined as the first appearance of the response. The optical placing of hands and feet may serve as an example. There are two types of final change: In the case of responses which disappear during development, such as the palmar grasp reflex, the final change was considered to have taken place when the response could no longer be elicited. As for the responses which manifested themselves in the course of development, or which showed evident changes, the assessment after which no gross changes in the response occurred was chosen as the moment of their final change. This was the case with the optical placing reactions of hands and feet.
3. A third criterion for the inclusion of an item in group III is that the developmental range is appreciable. This was concluded to be the case when the developmental range, defined as the period between first and final change, exceeded at least three to four examination-intervals. The majority of the items of group II, such as the items describing functions of the visual apparatus, were excluded from this group as they did not fulfil this criterion.

In table V the items of group III are listed. They are divided into two subgroups. The first group consists of items dealing with spontaneous behaviour which could be observed without specific manipulation of the infant. The second group is composed of items for which specific elicitation techniques are needed. The sequence in which the items are ranked within these groups is drawn up only for reasons of convenience and does not serve as a directive for neurological assessment.

**TABLE V**

**Items which showed fair differentiation and an evident developmental sequence (group III)**

*Observation of posture and motility*

spontaneous posture of the arms
spontaneous posture of the legs
spontaneous motility of the arms
spontaneous motility of the legs
spontaneous motility of the legs in vertical suspension
goal-directed motility of arms and hands
type of voluntary grasping
coordination of the upper extremities
posture of head, trunk and arms in prone position
locomotion in prone position
rollnig over from supine into prone position
rolling back from prone into supine position
spontaneous head lift in supine position
sitting up
duration of sitting
posture of the trunk during sitting
standing up
walking

*Reactions and responses*

rooting reflexes
asymmetric tonic neck response imposed
asymmetric tonic neck response spontaneous
palmar grasp reflex
reaction to push against the shoulder during sitting
following of an object with the eyes, and rotation of the head and trunk, when sitting
optical placing reaction of the hands
parachute reaction of arms and hands in prone suspension
optical placing reaction of the feet
foot sole response
acoustical orienting
the Moro reaction headdrop
lift
hit on the surface

The items of group III can be considered to show a gradual and protracted developmental course, which reflects a slow maturation of the neural mechanisms on which they are based. The meaning of this gradual and protracted development for a correct understanding of the maturing nervous system will be discussed in chapters XII, XIII and XIV.

## Observation of posture and motility

### Spontaneous posture and motility of arms and legs

*Procedure:* Dependent on his age the infant was placed in his crib or playpen in supine position. State 3 (posture) or 4 (motility).
The spontaneous postures and motility of arms and legs respectively were observed. The initial observation time was at least 3 minutes. The observation of posture and motility was continued during the whole procedure of assessment. The predominant posture and motility i.e. the posture and motility which could be observed most often, were recorded.

*Recording:*

The posture and motility of arms and legs were recorded separately. Observation of the developmental changes resulted in the following scoring scales:

**Spontaneous posture of arms and legs respectively:**

1. predominant flexion
2. predominant semiflexion
3. predominant extension
4. arbitrary posture i.e. posture without a predominant pattern.

Scores 2 and 4 were considered as first and final changes respectively of spontaneous posture.

**Spontaneous motility of the arms:**

1. neonatal alternating type of movements i.e. alternating flexion/extension movements with a rather stereotyped tempo and amplitude.
2. predominantly asymmetrical movements: asymmetrical, irregular flexion/extension movements of varying tempo and amplitude, usually accompanied by pro- and supination of the arms, often on one side of the body.
3. predominantly symmetrical movements: rather irregular flexion/extension movements, occurring on both sides simultaneously with varying tempo and amplitude. Pro- and supination less marked.
4. symmetrical and voluntary movements: goal-directed movements without a dominant flexion/extension pattern were considered as voluntary movements.
5. predominantly voluntary movements.

Scores 2 and 5 were considered as first and final changes respectively.

**Spontaneaus motility of the legs:**

0. neonatal alternating movements
1. predominantly asymmetrical movements
2. predominantly symmetrical movements
3. predominantly voluntary movements

Scores 2 and 4 were regarded as first and final changes respectively.

The prediction bands with the full ranges for the spontaneous posture of the arms and legs are presented in figures 6 and 7.

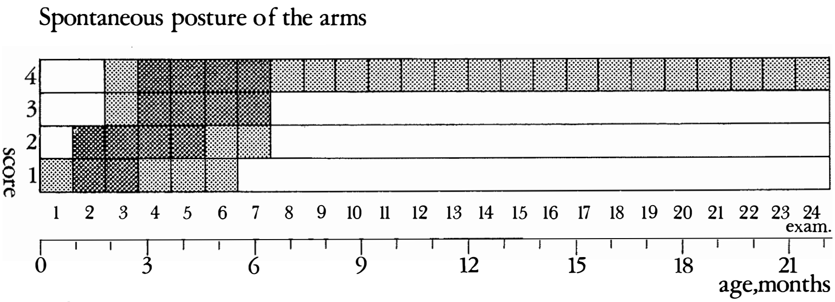



Fig. 6

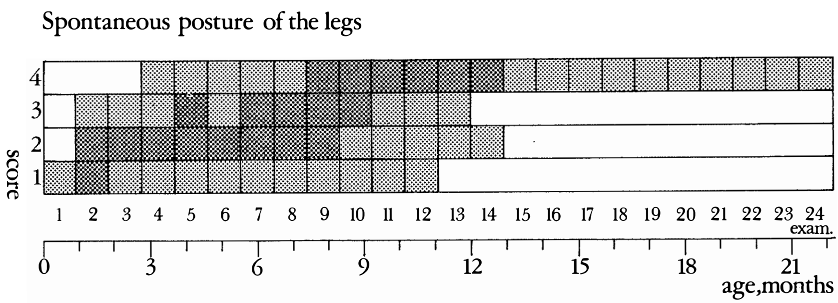



Fig. 7

The general confuguration of the prediction bands is comparable, although the prediction band of the posture of the legs shows a more protracted developmental course. This reflects the cranio-caudal gradient of functional development. The interindividual variability of development is illustrated by the occurrence of different scores at the same examination.

In only a few infants extension posture of the arms was found predominantly, the majority of the infants displaying arbitrary postures of the arms immediately after predominant semiflexion posture type.

On the basis of these data one may assume that usually a flexion posture of arms and legs occurs only during the first weeks of life as a predominant posture. The period during which semiflexion postures occur is much shorter in the case of the arms than in that of the legs. Arbitrary postures of arms and legs manifest themselves at about the same time

when goal-directed motility develops. Of course this happens much later in the case of the legs than in that of the arms. It reflects the sequence of the differentiation of motor programming in the brain. In the literature one generally agrees that the posture of arms and legs follows the developmental course described above (Ingram, 1959; Peiper, 1961). In the case of the arms, flexion-postures are rapidly replaced by voluntary postures, while in the legs an extension postures can be clearly distinguished as an independent phase. This should probably be regarded as partly belonging to voluntary motor activity because involved in or preparatory to voluntary standing behaviour.
In the present study extension of the legs was scored 4 as soon as it appeared to be part of voluntary motor behaviour. Thus Ingram's second extension phase, which he localizes at the end of the first year, can be considered as the beginning of arbitrary leg postures.

In the case of the arms the number of inconsistencies, i.e. relapses to a previous score, was much smaller than in the case of the legs. This may be due partly to the much shorter developmental course in the case of the arms, which reflects a faster development of differentiation of their motor programmes.
The great number of inconsistencies with respect to spontaneous posture of the legs also indicates the problem of standardization. Normal infants do not develop in accordance with a strictly sterotyped course. The scoringsystem is based on the most frequent occurrence of the various postures which can be distinguished.
It does not account for the great number of co-existing phases occurring intra-individually. Scores may be arbitrary to some extent because, in some cases, of two co-existing responses only one was scored.
In such cases the response type which occurred preponderantly was recorded or, if inevitable, an arbitrary choice was made. Inconsistencies partly result from this procedure; they reflect the variability of the (motor) expression of nervous activity.

As for the age of the first change or final change, the developmental range or the number of inconsistencies, there were no statistically significant differences between boys and girls.

A relationship between the final change of spontaneous posture of the arms (i.e. arbitrary posture) and the first appearance of voluntary grasping (i.e. palmar grasp type) was found ($r = .393$). The correlation coefficient is low, though significant ($p < 0.01$). A low but statistically significant correlation was found between the final change of spontaneous posture of the arms and the first change (i.e. first decrease in score) of the palmar grasp reflex ($r = .449$, $p < 0.01$).

The final change of spontaneous posture of the legs (i.e. arbitrary posture) was significantly related ($p < 0.01$) to the first change of items describing sitting behaviour and balance development during sitting, i.e. posture of the trunk during sitting, duration of sitting, response to push against the shoulder during sitting, and following an object with eyes, head and trunk during sitting. The first changes of these items are contaminated as they were scored only if the infant was able to sit free. The correlation-coefficients were more or less similar, ranging from .352 to .393. These relationships reflect that arbitrary use of the legs is a prerequisite for the development of steady sitting.

Spontaneous motility of the arms

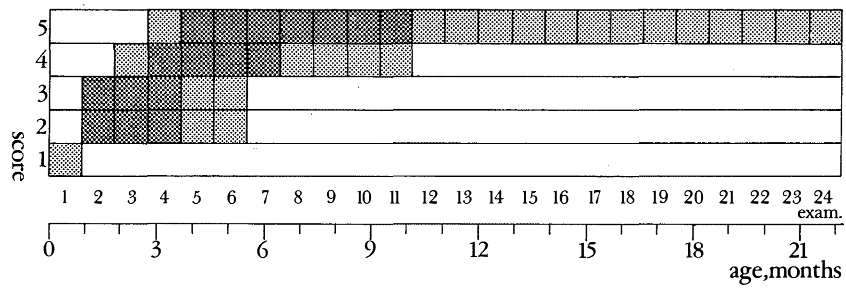



Fig. 8

Spontaneous motility of the legs

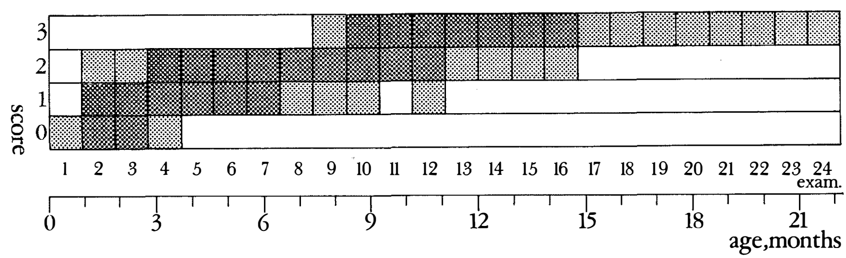



Fig. 9

In figures 8 and 9 the prediction bands are presented for spontaneous motility of the arms and of the legs. There is a protracted developmental course of the spontaneous motility of the legs compared with that of the arms. This is demonstrated by the conspicuous difference of the duration of neonatal alternating movements in arms and legs. However, a comparable sequence of development was found in arms and legs, the first change of the neonatal alternating type of motility being asymmetrical motility, followed by symmetrical previous to voluntary motility.

The infant started to watch his hands and play with them, and grasp for objects at about the same time when predominantly symmetrical motility of the arms manifested itself.

These motor activities consist of typical symmetrical use of arms and hands. They can be regarded as an example of the way in which a particular motor pattern becomes incorporated in goal-directed activities during their development. This point is also illustrated by the observa-

tion that in the majority of infants, during the development of arm motility, there was a developmental phase during which the symmetrical type of motility and voluntary movements were present in about the same quantity (score 4). Such a phase was not found for the legs.
During this phase especially the infants were busy playing with their hands or grasping their clothes, in all sorts of ways manipulating their environment with both hands at the same time. Beside this voluntary behaviour, they often showed symmetrical swaying movements of the arms, such as one might see in infants who suffer from a lack of stimulation, or in retarded infants.
In the literature the sequence of development of spontaneous motility of arms and legs (asymmetrical, symmetrical, voluntary) as described above is often attributed to the influence of tonic neck reflex-activity (Koupernik and Dailly, 1968). Asymmetrical tonic neck reactions occur in infancy with a peak frequency between the ages of two and four months, which is about the same period when asymmetrical arm motility is predominant.
In the case of the legs the period of asymmetrical motility lasts longer; it may be argued that tonic neck reflex influence is evident in leg posture and motility for a longer period of time than in the case of the arms. Still, this observable effect of tonic neck reflex activity is variable and inconsistent in normal infants (Paine, 1964; also Magnus and de Kleyn did not consider the comparable postures in normal infants to be identical with their asymmetric tonic neck reflex (cited by Vassella and Karlsson, 1962)). This would explain the large amount of interindividual variability of the developmental course of posture and motility. Indeed, it appears that at almost each assessment all the four scores could be found. The sams patterns of motility were present in the case of infants whose heads were centered, so that asymmetrical tonic neck effects were avoided. Moreover, no relationship was found between the first and final changes and the developmental range of spontaneous posture and motility of the arms and the legs on the one hand and of the asymmetric tonic neck reactions (spontaneous or imposed) on the other hand. The developmental sequence of patterns of motility as described above cannot be explained exclusively by the developmental course of tonic neck reflex activity; it appears to be based on more general central nervous organization.
Inconsistencies in the developmental course of the spontaneous motility of the arms occurred only in a minority of infants; as for the legs, about half of the infants showed at least one inconsistency during their developmental course. No statistically significant differences were found between boys and girls, contrary to Stambak's opinion cited by Koupernik and Dailly (1968) that in girls the asymmetrical motility of the arms would disappear earlier than in boys.

As was the case with the final change of the spontaneous posture of the arms, the final change of the spontaneous motility of the arms (i.e. predominantly voluntary movements) appeared to be related to the first

changes of type of voluntary grasping and the palmar grasp reflex ($r = .445$ and $.376$ respectively, $p < 0.01$).
The final change of the spontaneous motility of the legs (i.e. predominantly voluntary movements) was significantly related to the first change of items describing functional motor behaviour such as sitting, standing and walking and with the first change of the optical placing reaction of the feet.
Table VI lists these relationships, which are self-evident.

**TABLE VI**

**Correlation-coefficients ($p \leqq 0.01$) of relationships between the final changes of spontaneous motility of the legs and the first changes of some other items (Pearson Product-Moment correlations)**

| | | |
|---|---|---|
| Posture of the trunk during sitting | : | .413 |
| Duration of sitting | : | .431 |
| Response to push against shoulder during sitting | : | .420 |
| Following an object with eyes, head and trunk, sitting | : | .413 |
| Standing up | : | .659 |
| Walking | : | .598 |
| Optical placing of the feet | : | .505 |

They suggest that before these motor abilities can become manifest, the central nervous system must have matured sufficiently to allow for voluntary spontaneous motility.

**Spontaneous motility of the legs in vertical suspension**

*Procedure:* The examiner held the infant suspended in vertical position, supporting him under the shoulders. The spontaneous motility of the legs was observed, and the type of motility apparent most frequently was recorded. State 4.

*Recording:* The sequence of the development has been scored in the following way:
1. Neonatal, alternating type of movements.
2. Predominantly flexion movements of hip and knee joints.
3. Predominantly extension movements of hip and knee joints.
4. Predominantly asymmetrical motility, during which the legs showed irregular asymmetrical flexion/extension movements of varying tempo and amplitude.
5. Predominantly symmetrical motility consisting of flexion/extension movements of the hips and knees of both legs, of varying tempo and amplitude.
6. Predominantly arbitrary movements.

Scores 2 and 6 were considered as first and final changes respectively.

Goal directed movements of arms and hands

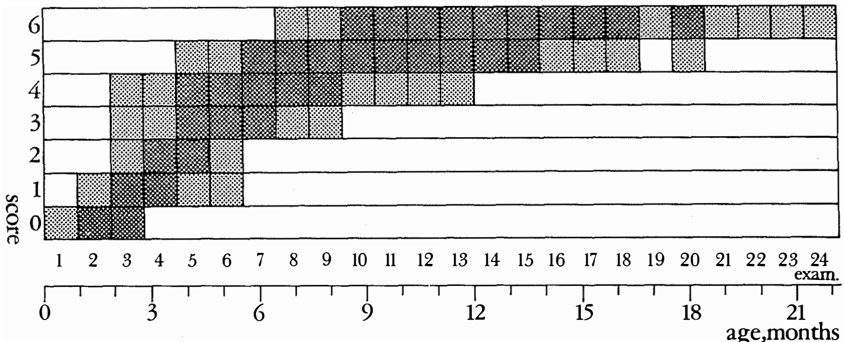



Fig. 10

The prediction band is presented in figure 10. The developmental course of the spontaneous motility of the legs in vertical suspension appears to be much protracted. The same overall pattern of development was found as in spontaneous motility of ams and legs in supine position.
However, in vertical suspension, after the first phase of neonatal alternating type of movements about one third of the infants showed flexion and/or extension movements of hips and knees predominantly before asymmetrical motility appeared.
Yet this was not the rule. While 10-15% of the infants persisted in extension movements until the 13th examination, i.e. until the age of about one year, 35 percent of the infants showed asymmetrical motility at the third assessment already; this percentage reached its peak (69%) at the sixth assessment, i.e. at the age of about 24 weeks.
From the fifth assessment onwards more than ten percent of the infants showed symmetrical motility of the legs, which type of motility reached its peak at the 11th assessment (about 44 weeks of age).
Arbitrary leg motility was observed in one infant as early as at the nineth assessment (36 weeks). From the tenth assessment onwards a rapidly increasing number of infants showed this type of motility predominantly; the 50th centile was exceeded at the age of about 64 weeks (14th assessment). The flexion and/or extension movements of hips and knees occurring immediately after neonatal alternating leg movements, may possibly be considered to reflect symmetrical vestibular influences on the motility of the legs in vertical suspension. There was no relationship with the occurrence of the positive supporting reaction.

Comparison of fig. 10, 31 and 21 (spontaneous motility of the legs in vertical suspension, optical placing reactions of the feet and standing up), shows that the optical placing reaction of the feet and standing up begin to manifest themselves at the time when the symmetrical movement type reaches its peak-frequency and begins to merge into voluntary movements of te legs (at about 44 weeks). From this one might conclude that the phase of symmetrical movement type of motor activity of the legs

reflects preparatory central nervous organization for the development of the motor ability of standing on both legs.
Actually the final change of the item spontaneous motility of the legs in vertical suspension was found to be closely related to the first changes of the optical placing reaction of the feet, standing up and walking (r's ranging from .715 to .798). The correlation-coefficients of its relationship with the first change in items describing sitting behaviour (posture of the trunk, duration, reaction to push against the shoulder and following an object with eyes, head and trunk) ranged from $r = .474$ to $.501$ ($p < 0.01$). This means that the moment when the development of effective balance during sitting sets in is (moderately) predictive of the moment at which in vertical suspension the infant is able to move his legs arbitrarily. The final changes of the development of sitting behaviour and motility in vertical suspension are related also (r's ranging from .464-.580, $p < 0.01$). If Kornhuber's (1973) theory about the role of the cerebellar nuclei in the motor organization is correct, the maturation of the cerebellar nuclei is of great importance for the development of the ability to maintain adequate postures of parts of the body (e.g. arms and legs) during voluntary motor behaviour. It is evident that this ability is needed during sitting behaviour. Arbitrary, i.e. voluntary use of the legs is important for standing and walking, in which obviously cerebellar mechanisms are also involved. In Kornhuber's opinion the cerebellar cortex is responsible for the regulation of fast movements, while the cerebellar nuclei undertake the regulation of the postures between the movements. Both types of regulation are important for a smooth control of voluntary movements. The relationships between the final changes of sitting behaviour and of motility in vertical suspension reflect the role of the maturation of cerebellar mechanisms in the development of these two motor patterns.
Nearly all the infants showed one or more inconsistencies in the scores during the developmental course of this item. The inconsistencies were distributed over the developmental course at random. They reflect the degree of intra-individual variability which can be regarded as characteristic of a normally developing nervous system, but they also illustrate the problems of operationalization of the several phases. There was no significant relation between the developmental range and the number of inconsistencies. Statistically significant differences between boys and girls were not found.

**Goal-directed motility of arms and hands**

*Procedure:*
Position of the infant: Supine position, during the first five months, sitting on his mother's lap subsequently (state 3 or 4). During the observation period it was observed whether the infant showed manipulative manual activity. Then the infant was presented with a small ovoid object (2 by 3 by 3 cm) which he was verbally encouraged to grasp. If he was able to hold the object in his hand, he was presented with a second one, and if he could hold the two objects he was presented with a third one.

*Recording:* Observation of the data resulted in defining the following sequence:

0. No goal directed motility of arms and hands.
1. Looking at and playing with the hands: the infant moved one or both hands in front of his eyes and watched them intently. Mutual touching and/or grasping of the hands were also scored 1.
2. Grasping objects. The infant approached the object presented with one or both hands and touched it with or without actually getting hold of it. Although both asymmetrical and symmetrical arm/hand motility could result in a score 1 or 2, dependent on the final result of the movement, it was found that playing with the hands and this type of grasping objects mainly involved symmetrical arm/hand activity.
3. Playing with the feet. The infant touched or grasped one or both feet, with one or both hands. This behaviour was scored separately because of being so spectacular, even though this score was obtained by only a minority of the infants and usually occurred in conjunction with score 2 or with one of the following scores.
4. Holding one object. The infant was able to grasp and hold one object with one hand.
5. Holding an object in each hand. After grasping the first object the infant was presented with a second one; he managed to grasp and hold this second object without dropping the first one.
6. Holding two objects in one hand. While holding an object in each hand, the infant was able to grasp a third object presented to him without dropping one of the others. In the majority of cases the infant shifted one of the objects from one hand to the other and grasped the third one with the free hand. Some of the infants shifted the object to the ulnar side of the palm, held it with palm and fingers and grasped the third object with the thumb and index finger of this hand.

A score 1 was considered as the first change, a score 6 as the final change.

The prediction band for goal-directed motility of arms and hands is presented in figure 11. Looking at and playing with the hands occurred in

Spontaneous motility of the legs in vertical suspension

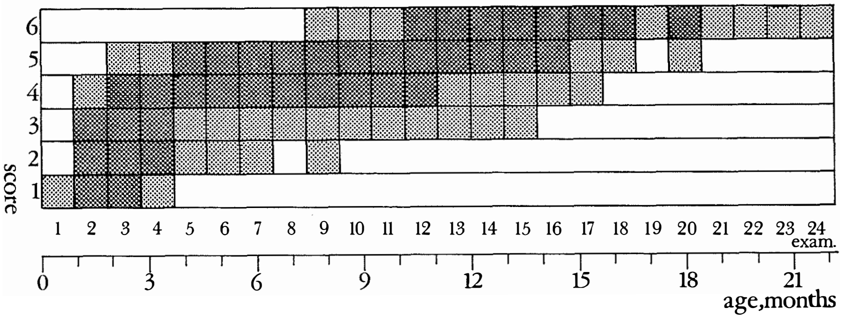



Fig. 11

more than 80% of the infants from the third examination onwards, i.e. from about the age of 12 weeks. This behaviour occurred earlier in only six percent of the infants.
A score 2, i.e. grasping objects, was obtained mainly during the fourth and fifth examination. At the sixth examination more than 80% of the infants had exceeded this phase. At about the same time the intensity of the palmar grasp reflex decreased. Actually the palmar grasp reflex may play an important role in reaching score 1 or 2. As the infant's one hand approaches an object or his other hand and touches it accidentally with his palm, this may result in a palmar grasp reflex, resembling voluntary grasping.
Thus the scores 1 and 2 do not only express grasping behaviour but also the intention of grasping.
In the period in which scores 2 and 3 are obtained by the majority of infants, observation of the spontaneous motility of arms and hands reveals predominantly symmetrical motility. Yet the infant's ability to direct his arm towards a specific goal shows that voluntary arm and hand motility are developing. Score 4, i.e. holding an object, can be considered as well-developed voluntary motor behaviour; at this time the palmar grasp reflex has decreased in intensity and the observation of spontaneous motility of arms and hands reveals voluntary movement patterns. Scores 5 and 6 reflect the differentiation of manual manipulative capacities. Score 5 means that the opening of the free hand in order to grasp an object is no longer accompanied by opening of the other hand which holds an object. It reflects the disappearance of associated movements as a result of maturation of the nervous system. A score 6 may be considered to reflect fully differentiated manual ability.
The time course of the different phases as shown in the prediction band is in accordance with the findings of Bruner (1970) and White (1970).

Figure 11 shows that the duration of the various phases increases when the scores become higher. While more than 80% of the infants obtain a score one during two examinations, it takes seven examinations before the final score 6 is reached by more than 80% of the infants.

Nearly half of the infants showed a relapse in score once. There were no statistically significant differences between boys and girls, neither with regard to the moment of the first change nor with regard to the final change, developmental range or number of inconsistencies.
The length of developmental range was related to the time of onset of the final change with a high correlation coefficient (r = .971). There was no relationship between the onset of the first change and the length of the developmental range. The first appearance of goal directed motility of the arms and hands has a much smaller variation range than the moment of stabilization (i.e. the final change). This explains the close relationship between developmental range and final change, which reflects the interindividual differential maturation of brain mechanisms

needed for goal directed abilities. It is evident that when the first goal directed motility of arms and hands manifests itself no prediction can be made concerning the duration of the developmental range of this type of manipulative behaviour.

The final change of goal directed motility of the arms and hands (i.e. holding two objects in one hand) showed a statistically significant relationship with the first change in items dealing with the development of steady sitting, comparable to the relationships found in the case of spontaneous motility of the arms (r's ranging from .401 to .440, $p < 0.01$). Still, the final change of goal directed ability of the arms and hands occurred considerably later than that of the spontaneous motility of the arms (cf. fig. 8 and 11). It may be assumed that steady sitting, i.e. established trunk-balance, advances independent and differentiated use of the arms.
There was no relationship with the development of type of voluntary grasping, neither with regard to the first change, nor to the final change or the developmental range. This might imply that the developmental course of goal directed motility of the arms and hands differs from that of fine differentiation of finger-use (which is implied in type of voluntary grasping); there was no relation in time; and apparently they are based on different brain mechanisms.
Keeping in mind Kornhuber's (1973) theory about the role played by the cerebral cortex in the motor organization, one might consider the final type of grasping as a typical moto-cortical function (see also Wiesendanger (1969), Lawrence and Hopkins (1972) whereas the goal directed motility of arms and hands would be mediated by non-cortical structures, i.e. the basal ganglia, brain stem and cerebellum.
The relationship between goal directed arm/hand motility and the development of steady sitting may be considered to support this hypothesis. The mediation of a steady and well balanced sitting posture must certainly be looked for in non-cortical structures.

Comparison of the number of inconsistencies in the developmental course of spontaneous posture and motility of the arms on the one hand and of goal directed motility on the other, shows that in the former developmental course there are less relapses to a previous phase than in the latter. The developmental ranges varied in length, but there was no significant relation between the developmental ranges and the occurrence of inconsistencies. In the case of the development of goal directed motility the inconsistencies mainly occurred during the second half of the developmental course, i.e. during the phases when differentiation of voluntary manual activity increased. This differentiation is a result of the increasing complexity of the underlying brain mechanisms; one might contend that the occurrence of inconsistencies reflects occasional lapses of a complex mechanism during its maturation.

The development of the ability to store an object before grasping and handling another one, as described by Bruner (1973), coincides with the development of the ability to hold more than one object in one hand, as described above. Actually the act of shifting an object to the ulnar side of the hand in order to get hold of a second object without losing the first, can be seen as a kind of storing, made possible by a neurologically determined differentiation of manual abilities.

**Type of voluntary grasping**

*Procedure:* During the assessment of goal-directed motility of arms and hands, the mode of grasping of both hands was observed consecutively. An ovoid object of 2 x 3 x 3 cm was used. State 4.

*Recording:*
0. No grasping of the object.
1. Palmar grasp: When grasping the infant used the whole palmar surface of hand and fingers.
2. Radial palmar grasp: the infant used the radial half of his handpalm, including thumb and indexfinger, predominantly.
3. Scissor grasp: the infant grasped the object between the volar surfaces of his extended thumb and indexfinger.
4. Inferior pincer grap: the infant grasped the object between the tip of his indexfinger and the volar side of his thumb.
5. Pointing: the infant appeared unable to grasp, he pointed and eventually touched the object with an extended indexfinger ("tipping"). Sometimes this pointing was followed by an inferior pincer grasp or a pincer grasp.
6. Pincer grasp: the infant grasped the object neatly between the tips of indexfinger and thumb.

The phase of pointing was observed in a very small minority of infants (at most 10%). Yet on closely interviewing the mothers, it appeared that the majority of the infants had shown this phase during a short period of time (often not more than one day), at a time when they could handle objects adequately. When pointing was observed during the assessment, it always occurred between the phases of the inferior pincer grasp and the pincer grasp. During the phase of pointing the infants were easily upset. This was confirmed by the mothers, who observed the same behaviour in their babies. As this phase seemed to be striking in at least some of the infants, it was included as a separate score. Scores 1 and 6 were considered as first and final changes respectively (fig. 12).

While at the third assessment a large majority of the infants (96%) did not manifest any grasping at all, during the fourth assessment half of the infants showed the palmar type of grasping, while four weeks later this was the case in 88% of the infants.
During development an increased differentiation of the developmental rate became apparent, which is reflected in the shape of the prediction bands. Especially during the last period of development i.e. the period in which the scissor and the inferior pincer grasp were preponderant, much overlap of scores was found. One third of the infants displayed a

Type of voluntary grasping

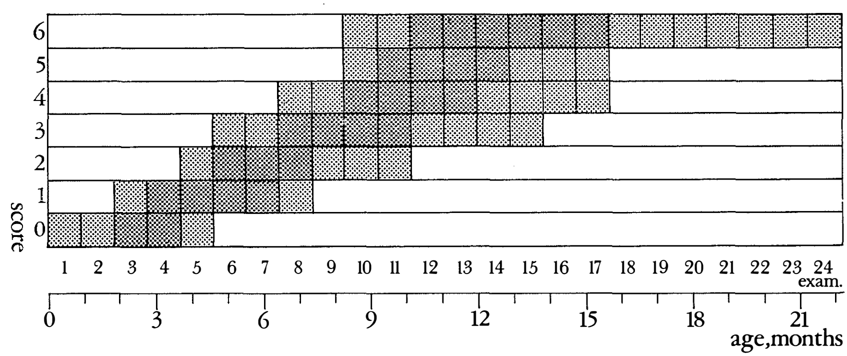



Fig. 12

neat pincer grasp at the 12th assessment (about 11 months), while nearly half of them reached this phase at the age of one year. More than 80% were able to use the pincer type of grasping during manipulative behaviour at the age of 14 months (15th assessment).

There was no statistically significant difference between boys and girls with regard to the moments of onset of first change or final change. In the boys there were three times as many inconsistencies as in the girls; this difference was statistically significant (Mann-Whitney U test, $p < 0.01$). There was a negative relationship between the onset of the first change and the length of the developmental range ($r = -.554$), while the latter showed a close and positive relationship with the final change ($r = .941$). This combination of relationships suggests that the moment of final stabilization of the type of voluntary grasping, as defined in this study, is more or less fixed; it is independent of the moment of the first expression of grasping.
As reported elsewhere (Touwen, 1971) there was no close relationship between the developmental course of the palmar grasp reflex and the type of voluntary grasping.
A statistically significant relationship with a low correlation coefficient ($r = .273$, $p < 0.05$) was only found between the first change of the palmar grasp reflex and the first appearance of voluntary grasping (palmar grasp type). Although the palmar grasp reflex may be partly responsible for the succes of the first attempt of grasping, this grasping cannot be regarded as being solely based on reflex mechanisms; it proves that a differentiation of voluntary manipulation has set in. Neither can this low relationship be considered as a strong support for the view that a decrease of the palmar grasp reflex is a prerequisite for the development of voluntary grasping.

The development of voluntary grasping has been described extensively by Halverson (1931, 1940), who distinguished 10 phases in the develop-

ment of prehension, reaching and differential manipulative behaviour included. He also concluded that there was a proximo-distal course of development, such as is apparent in the described developmental sequence. It stands to reason that the type of voluntary grasping is an important variable in developmental tests. Yet in these tests means or 50 centiles are usually given without ranges (an exception is the Denver Developmental Screening Test (Frankenburg and Dodds, 1967), which gives 3-95 centiles in addition to interquartile ranges) and the developmental sequence is often not taken into consideration, or it is presented only with key-ages. Moreover, the standardization of the techniques often varies widely. This hampers comparison with the findings of the present study. The phenomenon of the variation ranges tending to increase with increasing differentiation of type of grasping illustrates the importance of knowledge about the variation-ranges of the developmental phases.
From a neurological point of view the development of the type of voluntary grasping reflects the maturation of the moto-cortical and corticospinal mechanisms. As Wiesendanger (1969), in his extensive review of the function of the pyramidal tract, and Kornhuber (1973) have pointed out, the somato-sensory regulation of highly differentiated movements such as fine finger movements is a specific property of the motor cortex. The findings of Lawrence and Hopkins (1972) in the infant rhesus monkey suggest that the appearance of differentiated use of the fingers is related to the maturation of corticospinal connections. If this may be transferred to humans, the time schedule as presented in the prediction band of the development of type of voluntary grasping, may reflect the time course of the establishment of corticospinal connections in the human infant. It would be attractive to hypothesize that the phase of "pointing" marks the transition between "non-cortical" and "cortical" grasping mechanisms.
Low but statistically significant relationships were found, with r's ranging from .370 — .449 ($p < 0.01$) between the first change of voluntary grasping and the final change of spontaneous posture and motility of the arms, as reported in the paragraph on spontaneous posture and motility of arms and legs.

A statistically significant relationship was found between the final change of voluntary grasping and the first changes of standing up and walking ($r = .495$ and $.452$ respectively, $p < 0.01$). This may only mean that the time of onset of the development of standing and walking behaviour is related to the occurrence of fine differentiated use of hands and fingers. Yet one might argue that there is a sequential organization because this relationship suggests the priority of manual differentiation to motor development in vertical position. Teleologically this is a plausible sequence of development: the infant must be able to use his hands and fingers properly when he starts to pull himself into a kneeling position (first change of standing up) or starts to walk using both hands for support (first change of walking).

**Coordination of the upper extremities**

*Procedure:* The smoothness and adequacy of manipulation and playing behaviour was observed during the whole course of the assessment; at the end an overall semi-quantitative score was given.

*Recording:*

0. Badly directed swaying movements, the intended goal being missed repeatedly.
1. Well-directed movements, although overshooting occurred repeatedly. The goal was missed nearly half of the time, and when the intended movement succeeded, the quality of the movement was abrupt and hesitating as a result of badly controlled arm- and hand-motility.
2. Well-directed arm and hand movements without overshooting, of smooth and adequate quality. The intended movement succeeded most of the time.

A score 1 and a score 2 were regarded as the first and the final change respectively.

Coordination of the upper extremities

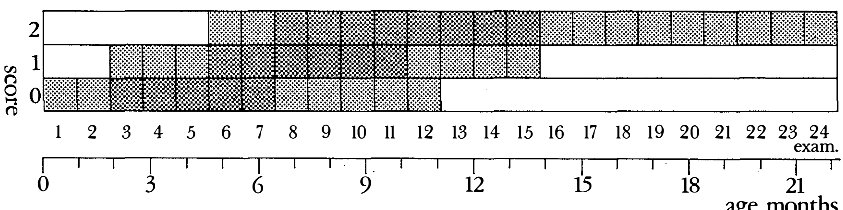



Fig. 13

The prediction band for the coordination of the upper extremities is shown in figure 13. It is clear that smooth and well-directed motility of the upper extremities is shown by more than 80% of the infants at the end of the first year. There were no consistent differences between boys and girls, although the number of inconsistencies was somewhat larger in the boys. There was a negative relationship, with a low correlation coefficient, between the time of onset of the first change and the duration of the developmental range ($r = -.449$, $p < 0.01$). An early onset of the development of goal-directed movements does not predict a rapid developmental course, i.e. an early establishment of good and stable coordination.

Gesell judged the development of coordination on the basis of specific performance, such as banging with toys, shaking, transfer from hand to hand, matching two objects, and so on (Gesell and Armatruda, 1947). In his view coordination was a derivative from specific motor patterns. It seems more adequate, however, to consider coordination as a function of a proper brain mechanism serving motor performances. It is possible that the neural mechanisms for coordination and those for voluntary motor performances develop rather independently. Voluntary motor

activity is based on cortico-spinal mechanisms, while coordination-mechanisms (i.e. cerebellar mechanisms) serve as a control system for carrying out the voluntary movement adequately and efficiently. An awkward and badly coordinated motor behaviour may be the result of impairment of the mechanisms for coordination, without the mechanisms for voluntary motor activity being impaired. This is the case in for instance ataxia.
This view, i.e. the development of coordination and voluntary motor behaviour are based on the maturation of different brain mechanisms, is supported by the fact, observed in the present study, that the development of the coordination of the upper extremities was not significantly related to the development of specific performances of hands and arms (e.g. grasping types or goal directed motility of the arms and hands).

A low, but statistically significant relationship ($r = .370$, $p < 0.01$) was found between the first change of the coordination of the arms (i.e. onset of development) and the final change (i.e. disappearance) of the spontaneously occurring asymmetric tonic neck reaction. This might imply that the latter would have a counteracting effect on the development of the former. This would be contrary to the opinion of Gesell, who considered the presence of the asymmetric tonis neck response an important promoting phenomenon for coordinated prehension (Gesell and Amatruda, 1947). The correlation coefficient is appreciably low, however. A relatively low though significant relationship ($r = .371$, $p < 0.01$) was found between the final change (i.e. stabilization) of the coordination of the arms and the first change of standing up (i.e. kneeling), which suggests that the infant needs an adequate coordination of the arms in order to be able to pull himself up into a kneeling position.

**Posture of head, trunk and arms in prone position**

*Procedure:* The infant was put on a flat surface in prone position. His head was centered. The posture of head, trunk and arms was described. State 4.

*Recording:*
1. The infant lifted his head and kept it lifted for some seconds, without using elbows or hands. The upper part of the thorax was either slightly lifted or not lifted at all. Absence of headlift in prone position did not occur among the infants of the study due to the selection criteria for neurological optimality.
2. The infant lifted the head and the upper part of the thorax, supporting himself on his elbows apparently. Still he did not topple over when this elbow support was pulled away.
3. The infant lifted his head and upper part of the thorax, part of the time supporting himself on his elbows, part of the time without supporting himself. In the latter case he extended and spread his arms in a planelike fashion (Illingworth, 1966, calls this latter position "swimming").

4. The infant lifted his head and upper part of the thorax without supporting himself on elbows or hands ("plane" or „swimming" position).
5. The infant lifted head and thorax, part of the time without any support, part of the time supporting himself on his (opened) hands and extended arms. Intermittently he supported himself on his elbows, which seemed to be a transition to support on extended arms. He toppled over if this support was pulled away.
6. The infant supported himself on his hands and extended arms almost exclusively. During this phase he might begin to draw his knees under his abdomen.
7. The infant supported himself on extended arms and flexed knees.

Scores 2 and 7 were considered as first and final changes respectively.

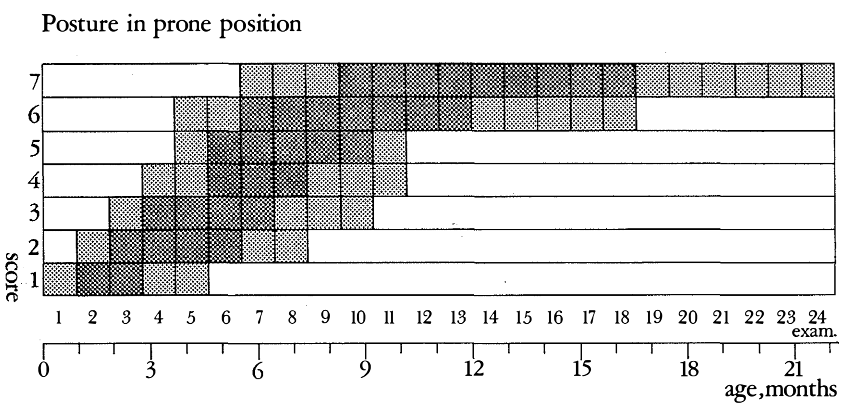



Fig. 14

The prediction band for this item is presented in figure 14.
Beside the intra-individual overlap of the several consecutive phases, represented by scores 3 and 5, interindividual overlap of scores is clearly evident.

At the second assessment six infants were well able to lift head and upper part of the thorax from the surface on which they were lying. About half of the infants showed this type of motor behaviour at the third assessment, and two thirds of them at the fourth assessment (about 16 weeks). At that time twenty two percent displayed "plane-like" or "swimming" postures.

Support on the hands was observed in some infants from the sixth assessment onwards (24 weeks). During the next twenty weeks there was a large overlap of phases. At the 14th assessment (about 13 months) more than 80% of the infants assumed the all-fours position, but a minority of infants persisted in an abdominal position until the 18th assessment (about 15 months).

One or two inconsistencies were found in 40 infants, without any difference between boys and girls. Neither was there a consistent difference between boys and girls as for the time of onset of the first change, the final change or the length of developmental range. There was no relationship between the time of onset of the first change and the length of developmental range, neither between the length of the developmental range and the occurrence of inconsistencies.

The final change of the posture in prone position (i.e. all fours position) was significantly related to the onset of the development of items dealing with motor behaviour during sitting (r's ranging from .364 to .383, $p < 0.01$) and standing, walking and optical placing of the feet (r's ranging from .690 to .461, $p < 0.01$). Appendix C shows the coincidence in time of these parameters. One may contend that the development of balance, as required for the all-fours position is a prerequisite for the development of adequate sitting. The ability to achieve an all-fours position reflects also an adequate use of motor control needed for an efficient development of vertical posture.

The variation-width of time of the final change of posture in prone position appeared to be much larger than that of the first change. The lengthening of the variation-width is mainly caused by a small number of infants (less than 20%) in whom the final change was retarded. This phenomenon of skewness of the distribution is found in the case of other items also. Its meaning was recognized by several authors, e.g., Hindley (1966, 1968), Frankenburg and Dodds (1967), Neligan and Prudham (1969a, b) by whom it was used to detect abnormally retarded children. As is clear from the fact that this phenomenon occurs in a group of low risk infants, such diagnostic conclusions based on time-scales are hazardous. Although it is likely that in random groups retarded infants may be largely responsible for this skewing, this argumentation cannot be inverted, especially if an infant shows a late development in only one or two items. As Neligan and Prudham stated, a combination of various items showing late development may have a greater predictive value with regard to (mental) development than the isolated finding that an infant sits, walks or speaks late (Neligan and Prudham, 1969b).

Illingworth (1966) states that generally the newborn is not able to lift his head from the couch and that he is hardly able to do so, for a few seconds, at the age of four weeks (Illingworth, 1966). In this group of low risk infants all of them could lift their heads for at least four seconds in the newborn period; they were able to support themselves on their elbows for at least ten seconds at about five weeks of age. These findings may be due to the selection criteria of the group.
Beintema (1968) also found that the ability to lift the head was consistently present during the first eight days of life from the second day onwards, in about half of the infants he examined. They belonged to a random hospital group.

In the present study the phase of "support on the elbows" was found to precede the "swimming" or "plane" phase, while Illingworth suggests an inverse sequence. Differences of operationalization may be responsible for this difference. This is very likely as on the whole the results with respect to the schedule of the "swimming" phase and the subsequent phases, in the present study, are in accordance with Illingworth's data.

**Locomotion in prone position**

*Procedure:* When in prone position, the infant was stimulated to move forwards, verbally and by an interesting toy held in front of him. Neonatal crawling movements and rolling were not considered.
State 4.

*Recording:*

0. No unequivocal change of spatial position.
2. Wriggling or pivoting movements, without specific use of arms and/ or legs, resulting in spatial displacement. Moving backwards was also scored 2.
2. Abdominal progression using the arms only.
3. Abdominal progression using the arms and legs.
4. Progresion by way of abdominal creeping and creeping on all fours, cf. on hands and knees.
5. Creeping on all fours exclusively.

Scores 1 and 5 were regarded as first and final changes respectively.

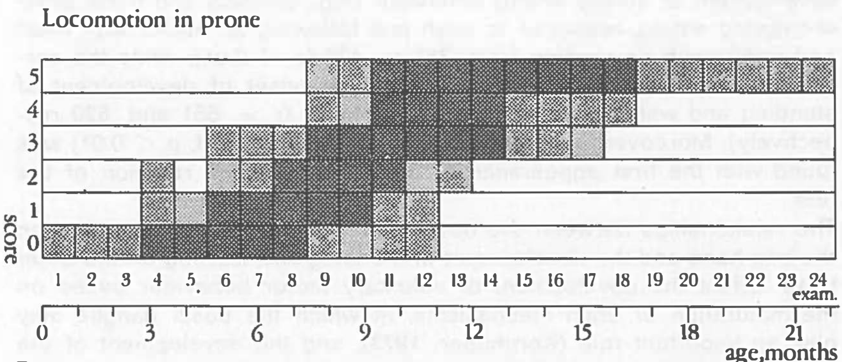



Fig. 15

The prediction band of locomotion in prone is presented in figure 15. The interindividual overlap is evident. Score 4 represents a spectacular intraindividual overlap of developmental phases.
In the present group there were no infants who did not show any

creeping behaviour. The phase of pivoting and wriggling movements arose at about the same time when the infant showed a "plane-like" posture in prone position. At about the time when the majority of infants could progress using their arms, in prone position they supported themselves on extended arms. Yet, for crawling purposes they made mainly use of their elbows. Only for creeping on all fours an extended arm posture was used.

About half of the infants showed inconsistencies, alike in boys and girls. The boys of this group showed the first change of locomotion in prone earlier than the girls; this difference, though small, was statistically significant ($p = < 0.01$, Mann-Whitney U test). Still boys and girls did not differ significantly as for the time of onset of the final change or the duration of the developmental range. This means that the girls caught up with the boys during development. There was a statistically significant relationship between the times of onset of the first and final changes ($r = .544$, $p < 0.01$). So the moment of the first change has a moderate predictive value with respect to the moment of the final change.

As reported elsewhere there is a close relationship between the mature phase of locomotion in prone and walking unsupported, while the relationship between the first appearance of pivoting movements and walking unsupported, is slight ($r = .650$ and $.277$ respectively; Touwen, 1971).
There were also low but statistically significant relationships between the mature phase of locomotion in prone and the first change of the development of steady sitting behaviour (e.g. duration and trunk posture during sitting, response to push and following an object with head and trunk) with r's ranging from .381 to .426 ($p < 0,01$), while the correlation coefficients of the relation with the onset of development of standing and walking were appreciably higher ($r = .651$ and $.620$ respectively). Moreover, a significant relationship ($r = .558$, $p < 0.01$) was found with the first appearance of the optical placing reaction of the feet.
The relationships between the development of locomotion in prone on the one hand and the development of standing and walking on the other hand reflect the development of voluntary motor behaviour based on the maturation of brain mechanisms, in which the basal ganglia may play an important role (Kornhuber, 1973), and the development of the connections between the brain and the spinal cord. In the spinal cord a well established motor organization for coordinated leg-motility is present at birth, as is shown by the so-called spontaneous crawling movements and stepping movements. However, at birth the mechanisms needed for maintaining balance during crawling or standing, although present, cannot express themselves because appropriate instrumentation (e.g. muscle power) is still lacking.

During development these so-called automatisms disappear, presumably due to influences from differentiating brain-stem structures. An inhibition of the automatisms is unlikely, as flexion and extension of the legs remains unimpaired, only the alternating rhythm disappears, though temporarily. It reappears in another form when the infant starts walking. Increasing muscle power and differentiation and organization of the cooperating vestibular and cerebellar mechanisms which result in the improvement of the maintenance of trunk and limb posture, are needed for the brain to generate efficient movement patterns. This is reflected by the relationships between the first change in the development of sitting posture and sitting balance, and creeping on all fours — as far as locomotion in prone is concerned — and by the relationships between the development of standing and of walking, which will be discussed later on. Thus an infant must be able to organize the posture of his trunk and limbs sufficiently, before he is able to creep on all fours, and he must be able to stand before he can start to walk. The increasing integration of the various brain areas (cerebellum, brain stem, basal ganglia, sensorimotor cerebral areas) during development is also illustrated by the relationship of the mature phase of locomotion in prone with the development of the optical placing reaction of the feet, in which cortical mediation (especially for directed and guided visual placing reactions as Hein and Held (1967) showed for kittens) is known to exist (Rademaker, 1931).

During the newborn period all the infants displayed neonatal crawling movements. These movements are supposed to disappear at the end of the first month of life. In the present study spontaneous neonatal crawling movements had disappeared indeed at the time of the second examination, i.e. at the age of about five to six weeks. At that time none of the infants yet showed pivoting movements as a first developmental appearance of locomotion in prone as defined in this study.

The sequence of abdominal crawling to creeping on all fours is well known. Still some infants never reach the phase of creeping on all fours, some infants never progress in prone at all and some infants progress only in a sitting position ("shuffling"). Neither of these phenomena occurred in the present study. According to Robson (1973) abdominal crawling (in his terminology: creeping, i.e. using the limbs for propulsion and sliding on the abdomen; scores 2 and 3 in the present study) is rarely observed in normal English infants, who generally start to progress on hands and knees much earlier than the infants of the present study appeared to do. In his opinion abdominal crawling is often observed in hypotonic infants, as a recognizable phase in their retarded development. In the present study from which hypotonic infants were excluded (cf. chapter III) all the infants showed abdominal crawling for an appreciable length of time. This apparent difference between English and Dutch infants emphasizes the necessity of taking population differences into account.

The developmental course of prone progression is rather lengthy, as is exposed brilliantly by McGraw (1943), who distinguished nine phases, seven of which are concerned with abdominal progression per se. She demonstrated both an inter- and intra-individual overlap of the consecutive phases, while in her material abdominal crawling took place as an appreciable developmental phase before creeping on all fours developed. In the present study intraindividual overlap is reflected only by score 4. In the majority of the items scores are based on the preponderance of a certain distinct motor behaviour, but in most cases various developmental phases coincided. This may account for at least part of the inconsistencies i.e. fluctuations found during the developmental courses. The global time schedule as established in this study is in accordance with McGraw's findings. A comparison with Gesell's scales is hardly feasible, as he only gives a mean key age of 40 weeks with a time range of four weeks to both sides without explaining the exact meaning of the variation range (Gesell and Amatruda, 1947).

Vojta (1968, 1974) has described "reflex-crawling" as a crawling pattern which can be elicited in normal infants by specific stimuli (forced movements of the arms and legs) until the age of onset of the first phase of locomotion in prone. In his opinion this "reflex-crawling" is of purely reflectory origin and never spontaneously displayed by the normal infant. Still he suggests that it's presence is a criterion for the normal development of (or preparation for the development of) locomotion in prone. This reflex-crawling may be comparable to the spontaneous movements of the newborn (which can be provoked and reinforced by pressure on the footsoles: Bauer-reaction), which result from spinal mechanisms. If appropriate stimuli are applied, it may be possible to provoke this motility in infants, but this does not imply that the movements elicited can be considered as reflexes. They merely indicate a latent capacity (latent after the first few weeks of life) of the infant's nervous system. They can be elicited by specific stimuli, but they would not manifest themselves spontaneously. This latent capacity achieves expression again, when crawling sets in during the development of voluntary locomotion in prone. According to Vojta the first appearance of locomotion in prone may take place in the fourth to sixth months of life, while creeping on all fours would be present in the third trimester of the first year. His data concerning the onset of the development of locomotion in prone are in accordance with the findings of this study. However, in the Dutch infants mature crawling, as defined in this study, occurred much later.

**Rolling over from supine into prone position**

*Procedure:* The infant was put on a flat surface in supine position; he was encouraged to turn over, for instance by the presentation of an interesting toy. The quality of his rolling behaviour was recorded. State 4.

*Recording:*

0. No rolling behaviour. The infant remained in supine position.
1. The infant turned from supine into prone position by way of axial rolling, initiated by head rotation, but without evident hip rotation.
2. The infant used rotation of the body on the pelvis during rolling behaviour.

Scores 1 and 2 were considered as first and final changes respectively.

Turning over into prone position

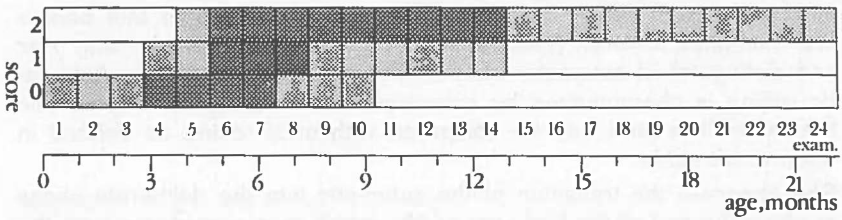



Fig. 16

The prediction band for rolling over from supine into prone position is presented in figure 16. In more than 80% of the infants the developmental course of the ability to turn into prone was brief, irrespective of the quality of the rolling behaviour. At the fifth assessment eight of the infants were able to turn into prone, while at the eighth assessment 92% of the infants could roll into prone position easily and smoothly. Trunk rotation during rolling showed a more protracted developmental course. While at the eighth assessment more than 80% of the infants displayed smooth rolling, only half of them showed trunk rotation. Trunk rotation had developed after 36 weeks in more than 80% of the infants. A close relationship was found between the moment of the final change and the length of the developmental range ($r = .743$) and also between the moments of the first and the final change ($r = .673$). This suggests that the moment of the final stabilization is more or less preprogrammed in time. The boys of this group started to turn into prone earlier than the girls; this difference was no longer evident at the moment of the final change, so that apparently the girls caught up with the boys during development.
The first change in the development of rolling over from supine into prone position (i.e. the first appearance of rolling) was significantly related to the mature phase of development of steady sitting, standing and walking, spontaneous posture of the legs in vertical suspension and the optical placing reaction of the feet, though with low correlation coefficients (r's ranging from .368 to .424, $p < 0.01$). It is not easy to interpret these relationships, unless in terms of general trends of development of motor phenomena displayed by a healthy organism. The correlation coefficients themselves are so low as to have little predictive value in individual infants.

The final change of rolling over from supine into prone position, reflecting differentiated use of trunk and leg musculature, showed significant relationships with the first changes of the items describing the development of steady sitting, standing, walking and optical placing reactions of the feet, with r's ranging from .423 to .543 ($p < 0.01$). These relationships can be interpreted along similar lines as the relationships of locomotion in prone and posture during prone position.

Koupernik and Dailly (1968) cite Stambak, who stated that turning from supine into prone starts at about four to five months, and also reported a sexdifference, boys showing more variations in this behaviour than girls. McGraw (1943) described the development of rolling over and distinguished automatic from deliberate rolling behaviour. Automatic rolling is characterized by extension movements of the spine and the extremities, and may be compared with axial rolling as defined in the present study.

She observed the transition of the automatic into the deliberate phase at about the end of the first year of life, which is in accordance with the findings of the present study, in which transition of axial rolling into turning over by way of evident trunk rotation was found at about the same time.

Vojta (1970) considers rolling from supine into prone position and back as "an inherited coordination complex of human motility during the earlier state of ontogenetic locomotion, presumably of spinal and lower brain-stem origin". Before rolling occurs spontaneously it can be elicited; then it is called "reflex-rolling" by Vojta. He suggests that in the case of a pathological development this "reflex-rolling" persists and blocks the development of spontaneous rolling. As in the case of "reflex-crawling", commented on in the paragraph concerning locomotion in prone, this use of the term "reflex" is confusing; it may suggest that the nervous system of the very young infant consists merely of a bundle of reflexes which gradually develop into "voluntary" motor behaviour. According to this concept the normal infant would be considered as functioning as a "reflex-being" at some period during his development, which evidently he does not. From birth onwards the infant is very well able to cope with his infantile needs, in a far more differentiated and variable way than would ever be consistent with the notion of a „reflex-being". Instead of being considered as a bundle of reflexes, the infantile nervous system must be seen as a complex information processing apparatus. Its latent capacities may sometimes manifest themselves in the shape of reflexes, provided that the adequate stimuli are given. The fact that specific stimuli may result in reflex-responses definitely does not imply that the total apparatus is composed of reflexes.

Moreover, Votja makes the usual mistake and considers reflex-rolling in brain-damaged infants as being identical with imposed rolling behaviour in healthy infants. In the case of a damage of the brain the nervous system is no longer homologous with an intact nervous system of the same age. Reactions and responses obtained from brain-damaged infants must be interpreted differently from those observed in healthy infants.

**Rolling back from prone into supine position**

*Procedure:* After the infant had turned over into prone position it was observed whether he was able to return into supine position. The examiner encouraged him to do so by showing an interesting toy and encouraging him to grasp it. When an infant was able to get into sitting position, he usually did not return from prone position into supine position, but started to sit up. The quality of rolling back into supine was recorded.

*Recording:*

0. The infant was not able to return into supine position.
1. The infant rolled back into supine axially.
2. The infant could turn from prone into supine position, sometimes by rotation of the trunk on the pelvis.
3. The infant returned into supine position exclusively by means of trunk rotation. If the infant did not return into supine, but got into sitting posture instead, as usually happened as soon as the infant was able to sit up independently, this was also scored 3 as trunk rotation is evidently involved in this process.

Scores 1 and 3 were considered as first and final changes respectively.

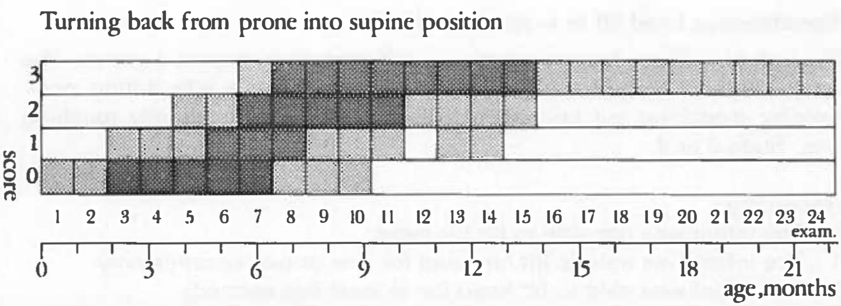



Fig. 17

The prediction band for this behaviour is presented in figure 17. The time of onset of the first change is about the same in the case of rolling into prone and rolling back into supine position. Trunkrotation during rolling back from prone into supine position started to occur about four weeks earlier than in the case of rolling over from supine into prone position. It occurred at about the time that in prone position the infant started to support himself on extended arms. It seems to be easier for an infant to push himself up on extended arms and then rotate the upper half of the body on the pelvis in order to turn on his back, than in supine position to lift head and shoulders and rotate them on the pelvis in order to turn over into prone.

More than 80% of the infants started to sit up from prone position at the 12th assessment, instead of returning into supine position.
Evidently trunkrotation is needed for this motor behaviour. In the case of rolling over into prone, at the ninth assessment trunk rotation was found in more than 80% of the infants while more than half of the group showed trunk rotation during turning back into supine at the eighth assessment. Perhaps the former process requires more complex cerebral programming than the latter.

During rolling back from prone into supine position there were more inconsistencies than in rolling from supine into prone position. There was no difference between boys and girls. In rolling back from prone into supine position boys were significantly earlier in displaying trunk rotation than girls (Mann-Whitney U test, $p < 0.01$). A relationship with a negative correlation coefficient was found between the time of onset of the first change and the length of the developmental range ($r = -.398$), while there was a close positive relationship between the moment of the final change and the developmental range ($r = .788$). This means that the length of the developmental range cannot be predicted by the moment of onset of this behaviour. The relationships between the final change of rolling back into supine position and the first changes of other items were comparable with those of the final change of rolling over from supine into prone position. Other relationships were not found.

**Spontaneous head lift in supine position**

*Procedure:* The infant was put on a flat surface in supine position. The examiner encouraged the infant to rise from supine into sitting position by stretching out his hands towards him without actually touching him. State 3 or 4.

*Recording:*
0. The infant was not able to lift his head.
1. The infant was able to lift his head for one or two seconds only.
2. The infant was able to lift head for at least five seconds.

Scores 1 and 2 were regarded as first and final changes of the response respectively.

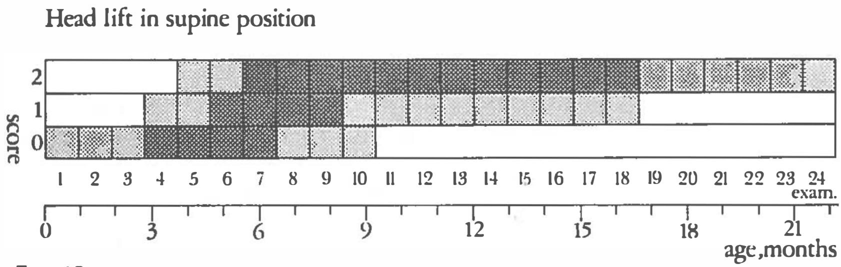



Fig. 18

The prediction band is presented in figure 18. In the majority of infants the ability to lift the head in supine position developed between the fifth and tenth assessment, i.e., between 20 and 40 weeks. The developmental course was rather rapid as is reflected by the slope of the prediction band. Inconsistencies occurred in a minority of infants and there was no difference between boys and girls. This was also not the case with regard to the time of onset of the first change and the final change and the length of the developmental range. The times of onset of the first change and of the final change were closely related ($r = .751$). One infant in this group did not lift his head until the 18th assessment.

The notion is plausible that the ability to lift the head in supine position plays a role in the development of the ability to sit up from supine. A comparison with the prediction band of sitting up (fig. 19) shows that a well-developed headlift in supine position is concurrent with a rather well-developed ability to sit up. Yet no relationship was found between the first and final changes of headlift in supine and sitting up respectively. Illingworth (1966) also described the spontaneous head lift in supine position as a complemental phenomenon occurring during a later stage of the development of sitting, and reported that it takes place at about 28 weeks. The present findings are in agreement with these data.

The ability to lift the head in supine position reflects the differentiation of vestibular brain mechanisms, which enable the infant to oriënt his head in space. Evidently increase of muscle power also plays a role. The notion of the significance of differentiating vestibular mechanisms for this motor behaviour is supported by the fact that the infant's ability to control his head position at various angles when lying in prone increases at about the same time. In this instance the influence of vestibular mechanisms is evident; the infant had been able to lift his head from birth onwards, which means that in prone position the muscle strength was great enough for this purpose.

The final change of the headlift in supine position was significantly related with the onset of the development of walking ($r = .460$, $p < 0.01$); the correlation coefficient of the relationship with the onset of standing up did not reach this level of significance.

**Sitting up**

*Procedure:* The infant was put on a flat surface in supine position. The examiner grasped the infant's wrists and encouraged him to sit up, helping him, if necessary, by pulling at his hands.

Every kind of active flexion of the infant's elbows was regarded as a manifestation of active sitting-up behaviour, and recorded. The reflex-flexion of the elbows during the traction-test in the newborn was not regarded as active flexion and consequently as a part of voluntary sitting-up behaviour. State 3 or 4.

*Recording:*

0. No active flexion of the elbows and/or retraction of the shoulders during pulling into sitting position. The head remained in one line with the trunk.
1. Slight active flexion of. the elbows and/or retraction of the shoulders, with evident flexion of the head. The infant was not able to reach a sitting position without the examiner's help.
2. Evident active flexion of the elbows and retraction of the shoulders. The infant still needed the examiner's help during the last part of the movement. Evident head and trunk flexion.
3. The infant was able to sit up without any active help of the examiner.

Scores 1 and 3 were regarded as indicators of first and final changes respectively.

Sitting up

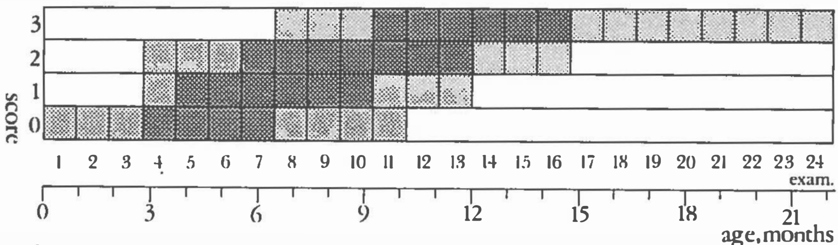



Fig. 19

The prediction band for sitting up is presented in figure 19. The variation range for the different phases is considerable. Although a small minority of the infants was able to sit up independently at the age of about 32 weeks, about 50% of the infants could not do so until the end of the first year of life. At the age of about 14 months more than 80% of the infants managed to sit up independently. In this group of low risk infants the full range for sitting-up independently lasted 36 weeks; some infants were able to sit up without help as early as at about 32 weeks of age, while some others managed to do so at about 65 weeks.

About half of the infants showed inconsistencies during the developmental course of sitting up. There were no differences between boys and girls. Compared with the boys, the girls of this group showed the first appearance of sitting up behaviour significantly later ($p < 0.01$, Mann-Whitney U test). In the girls also the final change took place somewhat later than in the boys; this difference was only significant at a 5% level (Mann-Whitney U test). The mean developmental ranges did not vary significantly as for boys and girls. The moment of onset of the first change was weakly related to the length of the developmental range ($r = -.382$, $p < 0.01$). Thus the length of the developmental range can only be predicted from the age at which the first change occurs to a limited degree. There was no relationship between the number of inconsistencies and the length of the developmental range.

There was a close relationship between the final change of sitting up, (i.e.: sitting up without help) and the onset of the development of standing up and walking (r = .805 and .812 respectively). Hardly any relationship was found between the final change of sitting up and the development of the response to push against the shoulder during sitting or following an object with the eyes and rotation of the head and trunk during sitting. It is evident that balance is developed before an infant is able to sit up independently. This notion is supported by the relationship between the duration of sitting and the onset of the development of the response to push against the shoulder, while at the same time the duration of sitting and sitting up are not related (see next paragraph.

The neonatal flexion of the elbows occurring during the tractiontest persisted in at least half of the infants until about ten to twelve weeks. This reflex-flexion gradually merged into active flexion or was replaced by extension of the arms without any active attempt to sit up. In more than half of the infants during some period of their development extension of the arms was found during pulling into sitting position, before active flexion occurred as the first appearance of voluntary sitting up. The selection criteria for the present group precluded the occurrence of head lag resulting from hypotonia during the traction test. The head lag occasionally found in normal infants during the first months when they are pulled into sitting position (McGraw, 1943; Illingworth, 1966), was not observed either. In her description of the developmental course McGraw included sitting up by way of turning on the side in prone position. This would occur after the phase of evident active elbow flexion (score 2), although she emphasized the considerable overlap between phases. In the present study the standardization may account for the protraction of phase 3, which in McGraw's study is replaced by turning and rolling patterns. There is no discord between McGraw's findings with respect to the ability to sit up independently and those mentioned in the present study.

**Duration of sitting**

*Procedure:* The duration of sitting unsupported on a flat surface was counted in seconds, irrespective of the way in which the infant reached sitting position. State 3 or 4.

*Recording:*

0. The infant was not able to sit without support.
1. The infant was able to sit free for some seconds.
2. The infant was able to sit free for about 30 seconds.
3. The infant was able to sit free for about one minute.
4. The infant was able to sit free longer than at least one minute.

Scores 1 and 4 were considered as the first change and the final change of sitting unsupported respectively.

Duration of sitting

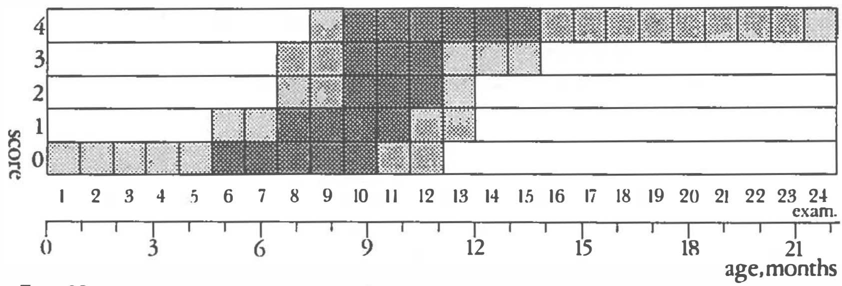



Fig. 20

The prediction band of sitting unsupported is presented in figure 20. At the eighth assessment about one third of the infants was able to sit unsupported for at least some seconds, i.e. at about the age of 32 weeks. Some infants were already able to sit up independently at the same age. Still generally the ability to sit up without help developed several months later. This confirms the common finding that manu infants are able to sit unsupported before being able to get into sitting position without help. The prediction band makes clear that in the majority of the infants the duration of sitting unsupported increased rapidly. Still the variation-width was considerable. The scores 2, 3 and 4 showed much overlap, so that one may conclude that the ability to sit free for about half a minute indicates a fully developed ability to sit unsupported. A comparison of the prediction bands of figures 19 and 20 shows an overlap also which implies that an infant who is able to sit unsupported for longer than half a minute, very soon will be able to sit up independently as well. Inconsistencies in the duration of sitting occurred in a small minority of the infants.

There were no consistent differences between the boys and the girls of this group. A close statistical relationship ($r = .695$) was found between the times of onset of the first change and of the final change. This means that to some extent the moment of the first change is predictive of the moment of the final change, i.e. stable sitting. At the same time a negative relationship ($r = —.479$ $p < 0.01$) was found between the first change and the developmental range, which seems to be contradictory. Presumably two different subgroups of infants should be distinguished: one subgroup of infants in whom the development of the ability to sit free for a certain amount of time has a rather fixed developmental range as the first appearance of this ability predicts the moment of stabilization, and another subgroup of infants in whom this is not the case. Actually, plotting "first change" against "final change" and "developmental range" respectively displays these two subgroups (fig. 21 and 22).

In the boys a positive relationship was found between the first changes of the ability to sit up and the duration of sitting (r = .696). There was no such relationship in the subgroup of the girls. The last changes of sitting up and duration of sitting showed a statistically significant relationship in the case of both boys and girls, though to a greater extent in the case of the boys (r = .805, r = .470, recpectively). It is not surprising that these relationships are found as comparable brain mechanisms for balance control are needed in the case of sitting up independently and sitting free. Still the ability to sit up as defined in this study,

**Duration of sitting** r=.70 N=50

| First change \ Final change | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|
| 13 | | | | | | 22 19 | | 5 |
| 12 | | | | | | 33 | | |
| 11 | | | | 25 27 36 38 41 42 | 17 44 | 12 | | |
| 10 | | | 49 | 13 15 20 21 26 28 | | | | |
| 9 | | 48 | 7 24 50 52 | 16 | 9 29 32 | | | |
| 8 | 8 | 1 23 4 46 6 51 | 2 10 14 45 | 30 37 | 11 40 | 31 | | |
| 7 | 34 | 18 35 | | 3 | | | | |
| 6 | 43 | | | | | | | |

Fig. 21:

The relation between the first changes and the final changes of duration of sitting (N = 50).
Vertical axis: assessments during which the first changes occurred.
Horizontal axis: assessments during which the final changes occurred.
Case numbers are plotted in order to be able to identify the infants.
It appears that case-number 9, 29, 32, 30, 37, 11, 40, 31 and 3 are localized somewhat beside the cloud of the rest of the case-numbers.

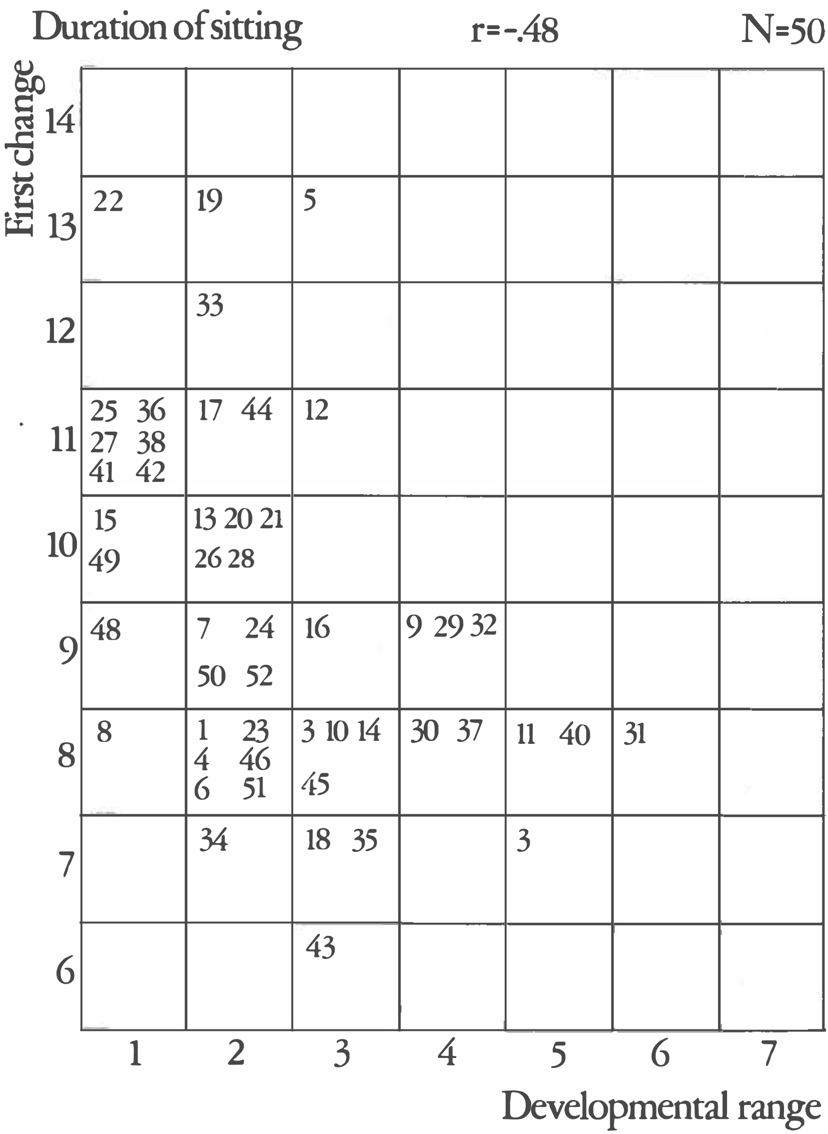



Fig. 22:

The relation between the first changes and the developmental ranges of duration of sitting (N = 50).
Vertical axis: assessments during which the first changes occurred.
Horizontal axis: length of the developmental ranges expressed as the number of four-week periods between the first and the final change.
Case numbers are plotted in order to be able to identify the infants.
The cases 9, 29, 32, 30, 37, 11, 40, 31 and 3 appear to be responsible for the statistical significance of the computed Correlation-Coefficient.

is based mainly on active power, while sitting unsupported for a few seconds also requires a development of balance.

As stated above the boys started to sit up with help earlier than the girls. Yet as far as the duration of sitting is concerned there was no difference between boys and girls. This may imply that there is more active power in the boys, but that in the girls the development of balance is similar or even faster. Gesell, and after him Illingworth, state that momentarily the "normal" infant sits without the examiner's help at 28 weeks, while he is able to sit free for a long period of time at 40 weeks (Gesell and Armatruda, 1947; Illingworth, 1966). These dates are much earlier than those presented in the present study.

When the age of the final change, i.e. sitting free for longer than one minute, in the present study is compared with the centiles of Neligan and Prudham (1969) a substantial difference also appears which for the medians amounts to about one month and a half. As the definitions of sitting free do not vary, this difference is suggestive of population differences, although different modes of data collection and analysis may also be partly responsible (Touwen, 1971).

**Posture of the trunk during sitting**

*Procedure:* The posture of the infant's trunk during sitting without support was described, irrespective of the way in which the infant reached sitting position.

*Recording:*

0. The infant was not able to sit without support.
1. The infant sat with rounded back and supported himself on his arms.
2. The infant sat with rounded back without supporting himself on his arms.
3. The infant sat with straight back without evident lumbar kyphosis or lordosis.
4. The infant sat upright with evident lumbar lordosis.

Scores 1 and 4 were considered to reflect the moments of the first and final changes respecively.

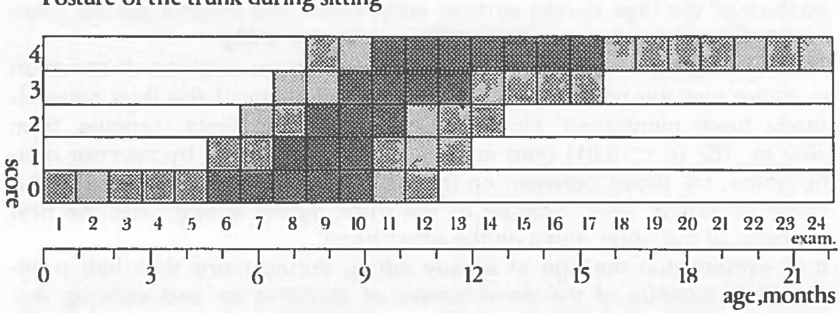



Fig. 23

The prediction band of trunk posture during sitting is presented in figure 23. The prediction bands of the duration of sitting and the posture of the trunk during sitting are comparable with regard to both shape and localization on the time axis. This implies that parallel to the increase of the duration of sitting, the posture of the trunk during sitting develops rapidly. One may argue that the development of erect posture during sitting reflects the development of balance which in its turn results in an increase of the duration of sitting. In about one fifth of the infants an inconsistency was found during the developmental course of posture during sitting; there were no differences between boys and girls.
There was a statistically significant relationship between the time of onset of the first change and the final change ($r = .509$, $p < 0.01$), while the relationship between the time of onset of the first change and the length of developmental range was negative ($r = -.492$, $p < 0.01$). This may be accounted for in the same way as was done in the case of duration of sitting.

In the majority of the infants the ability to use one or two hands voluntarily during sitting developed in the period of time when the infant was able to sit longer than half a minute with a straight back. In the majority of the infants the posture of the legs during sitting showed a specific developmental course: the infants started to sit with flexed legs, while subsequent extension of the legs coincided with the ability to sit longer than half a minute with a straight back. In the majority of infants an arbitrary posture of the legs, i.e. a posture of the legs without a specific flexion or extension pattern, occurred only if the infant was able to sit unsupported for more than one minute with a neatly hollow back.

The moment of onset of the first change of the items "duration of sitting" and "posture of the trunk during sitting" were significantly related to the final change (the stabilization) of balance development during sitting ("response to push against the shoulder" and "following an object with the eyes and rotation of the head and trunk"), with correlation coefficients ranging from .587 to .652 ($p < 0.01$). The two items mentioned were closely interrelated. Low but still significant relationships were found with standing free and walking unsupported and with an arbitrary posture of the legs during vertical suspension and evident optical placing of the feet (r's ranging from .368 to .499, $p < 0.01$).
The relationships with the final changes of prone position, locomotion in prone and the posture and spontaneous motility of the legs have already been mentioned. Higher correlation coefficients, ranging from .480 to .762 ($p < 0.01$) (see appendix D), were shown by reverse relationships, i.e. those between on the one hand the final changes of "duration of sitting" and "posture of the trunk during sitting" and the first changes of the other items on the other hand.
It is evident that the age of steady sitting during more than half a minute is predictive of the development of standing up and walking. Actually all the relationships mentioned reflect the more or less closely

related development of a set of functions in which primarily postural mechanisms of head, trunk and legs are involved.
The actual time schedule (appendix C) together with the relationships between the first and final changes of the various items points at a schematic developmental course, in which standing and walking are preceded by steady sitting, while the development of balance, reflected by sitting behaviour, should at least have started before the all-fours position and creeping on all-fours canbe achieved.

**Standing up**

*Procedure:* The way in which the infant tried to get into standing position was observed and described. If necessary he was verbally encouraged but not touched. State 4.

*Recording:*

0. The infant was not able to stand up.
1. The infant was able to get into a kneeling position, while supporting himself with one or both hands.
2. The infant was able to get into a standing position while supporting himself during standing, He was not able to sit down without help.
3. The infant was able to get into a standing position while supporting himself during standing; he was able to sit down without help.
4. The infant was able to stand free.

Scores 1 and 4 were considered to reflect the first and final changes respectively.

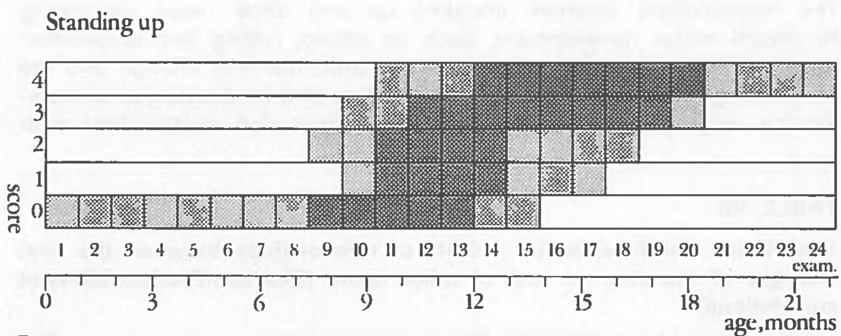



Fig. 24

The prediction band for standing up is presented in fig. 24. It shows a wide overlap of the different phases. The first appearance of standing with support showed a variation range from about 36 to about 72 weeks. Although one infant could stand free at about 44 weeks, 80% of the infants had reached this developmental phase at about one and a half year of age. The median for standing free was found at the age of about 65 weeks (c. 15 months). The median for standing with support was found at about one year.

André-Thomas describes the period during which the infant is not yet able to stand free without losing balance, as a period of physiological astasia and abasia, implying motor and postural incompetence. He stated that this is perfectly normal in infancy and mentions ultimate time limits of 15-18 months of age (André-Thomas and St. Anne Dargassies, 1952). However, the use of terminology with a specifically pathological meaning belonging to (adult) neurology should not be applied to the normal motor behaviour of infancy. Moreover terms like astasia and abasia are disproportionately "heavy" for a description of relative imbalance occurring during the development of balance and trunk-coordination in standing position.
The girls started and reached the final change later than the boys, while their developmental range was also more protracted; these differences did not reach statistical significance (Mann-Whitney U test). There were hardly any inconsistencies in the development of this motor behaviour. A statistical relationship was found between the moments of onset of the first change and the final change ($r = .563$, $p < 0.01$) and also between the moment of the final change and the length of the developmental range (.765). It seems as if standing up (reflected by the relationship between the first and final changes) develops in accordance with a kind of time-tally; as soon as development sets in a rather fixed amount of time is available for reaching the final change. At the same time environmental conditions may effect the developmental course (as reflected by the close relationship between the final change and the developmental range).

The relationships between standing up and other items describing functional motor development, such as sitting, rolling and locomotion in prone, have been discussed already. Both the first change and the final change were closely related to the first and final changes of walking (r's ranging from .794 to .820). There were also relationships with

**TABLE VII**

**Correlation coefficients ($p \leq 0.01$) of relationships between the first changes of standing up and of other items (Pearson-Product-Moment correlations)**

| | |
|---|---|
| response to push against shoulder during sitting | .724 |
| following an object with eyes, head and trunk during sitting | .703 |
| optical placing of the feet | .697 |
| type of voluntary grasping | .495 |
| palmar grasp reflex | .456 |
| parachute reaction of arms and hands | .438 |
| footsole response | .400 |
| coordination of upper extremities | .371 |

some reactions (table VII). Kneeling, defined as the first change of the development of standing up, was related with well developed balance reactions in sitting position and with adequate optical placing of the feet. It is not surprising that these relationships were found as in all these instances well guided motor control of trunk and legs is required, implying a differentiated integration of brain mechanisms promoting this motor control, i.e. cerebellum, brain stem and basal ganglia. The relationships with the final change of type of voluntary grasping (i.e. pincer grasp), palmar grasp reflex (i.e. complete dissolution), parachute reaction of the arms and coordination of the upper extremities suggest that a differentiated use of the hands is important for the development of voluntary rising into standing position; they reflect the importance of the development of corticospinal connections in this context. The relationship with the final change of the footsole response can be considered as evidence of an increase of suprasegmental influence on spinal mechanisms, due to the maturation of cerebrospinal integration, as a result of which the dominance of extensor activity in the motility of the toes is shifted to the flexor side (Kugelberg, Eklund, Grimby, 1960; Grimby, 1963 a+b; Gassel, 1970).

The finding that standing free is related to the onset of the development of balance during sitting and optical placing of the feet (r's ranging from .360 to .522, $p < 0.01$) points at the intricate relationships between the brain mechanisms involved in the development of motor patterns which nivolve active muscle power, balance and voluntary use of muscular activity.

**Walking**

*Procedure:* The infant's trials to progress on his feet were observed and recorded. If the infant was not able to walk without support, his mother was asked to help him. State 4.

*Recording:*

0. The infant was unable to walk.
1. The infant could walk if his mother held him by both hands.
2. The infant could walk if his mother held him by one hand.
3. The infant walked free for a few paces.
4. The infant walked free for at least seven paces consecutively.

Scores 1 and 4 were regarded to reflect first and final changes respectively.

The surface on which the infant walked was standardized as much as possible, dependent on the home environment. For the majority of infants a soft surface was available.

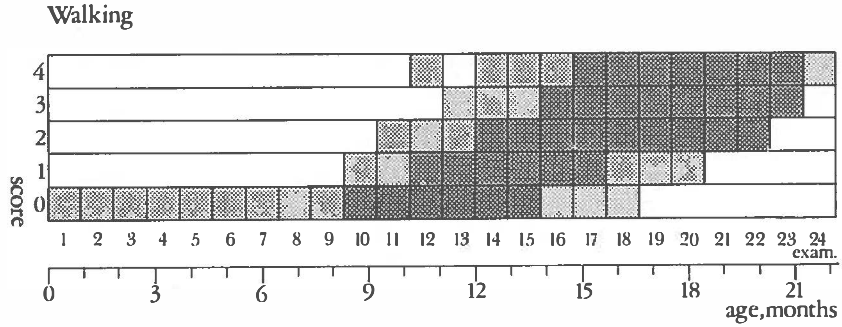



Fig. 25

The prediction band for walking is presented in figure 25.
The width of the last part of prediction band is not reliable, as walking for seven paces consecutively was the criterion for the finishing of the follow-up study and the prediction bands were not corrected for 51 infants.
In this group of low-risk infants the width of the variation-range is conspicuous. The median for walking with the support of both hands was found at the age of about one year while the 50th centile for walking free was found at about 64 weeks (16 months).
There were hardly any inconsistencies during the development of this motor behaviour. In the girls the first change occurred later than in the boys; this difference did not reach a 1% level of confidence (Mann-Whitney U test). Walking free was achieved significantly earlier by the boys than by the girls (Mann-Whitney U test, p. $< 0.01$). In the girls the duration of the developmental range was more protracted than in the boys; this difference was not statistically significant. In the girls there was a close relationship between the time of onset of the first change and the final change ($r = .877$); this relationship was also found in the boys, though with a lower correlation coefficient ($r = .678$). Moreover, in the boys there was a low negative relationship between the time of onset of the first change and the lenght of developmental range ($r = — .347$, $p < 0.01$), which was not found in the girls ($r = .055$).
It is difficult to account for this difference in relationships between boys and girls. Several factors may play a role. Possibly the genetic differences, based on endocrine influences, are partly responsible, and result in greater muscular strength in the case of the boys. Also the hormonic constellation may influence brain maturation differentially. Various culturally conditioned expectancy patterns with regard to male and female behaviour may affect child rearing patterns, the result of which may manifest itself already in infancy.

In the total group (i.e. boys and girls taken together) the height of the correlation coefficients of the relationships between the first and final changes ($r = .794$) differed from those of the developmental range and final change ($r = .493$). This implies that the time needed for the development of walking free, is more or less fixed, and that the moment at

which the first manifestation of walking occurs predicts the age at which walking free is achieved to a reasonable extent.
A close relationship was found between the development of walking and of standing up. This relationship reflects the differentiation and integration of brain mechanisms needed for the development of motility in a vertical position, in which process cerebellar, brain stem, basal ganglia and corticospinal mechanisms are involved. The maturation of postural (including equilibrium) mechanisms must take place before the ability of bipede progression in space can be achieved. A comparison of the characteristic features of standing and walking indicates the differentiation of motor organization as reflected in the latter function.

The relationships between walking and other items resemble those mentioned in connection with the development of standing up; they can be interpreted analogically.
A comparison of the present data with reports found in the literature concerning the age of walking free reveals considerable differences. While for this ability Gesell and Bühler give a range from 15-18 months (Bühler and Hetzer, 1932; Gesell and Armatruda, 1947), Illingworth mentions 13 months, the Denver Developmental Screening Test gives 12.1 months as a median, and Bayley in her crosssectional sample even 11.8 months (Illingworth, 1966; Frankenburg and Dodds, 1967; Bayley, 1969). Neligan, using the same operationalization as is applied in the present study, mentions 12.8 months as a median (Neligan and Prudham, 1969).
The eventuality of population differences has to be taken into regard apart from methodological differences in the collection of data and in the mode of analysis. Hindley emphasized this point in his comparison of five European longitudinal samples; he drew attention to the finding that no significant sex differences (or even tendencies) for walking free could be found in these samples (Hindley et al, 1966).
This is contrary to the present findings, which show slight but significant differences between boys and girls.

Also a comparison of the full ranges of walking without support reveals differences: the Denver Developmental Screening Test mentions a range from 9.8 - 14.3 months (5 - 95%), Zdánska-Brincken and Wolanski (1969) give about 10 - 14.5 months (10 - 90%), Neligan 9.7 - 15.8 (5 - 90%) while in the present study a range of 13.5 - 18 months was found (10 - 90%). Sample composition (cf. Neligan's conclusion that lower class infants walk earlier than upper class infants), standardization and operationalization (observation versus mother's report; environment and time of the day) may account for part of these differences.

Attention must also be paid to Neligan's remark that there is a protracted course to be observed in that part of the centile curve which specifically represents the infants whose ability to walk free was retarded. In a population study this protracted course of the centile curve may be attributed to "late walkers", recruited from deviant infants. However,

a similar phenomenon was found in the present study from which deviant infants were carefully excluded.
In the case of five infants the rounding off of their follow-up had to be postponed for 16 weeks due to a late achievement of walking free. These infants are responsible for the increase of the variation-width of walking free on the right hand side. Yet they were quite inconspicuous from a neurological and behavioural point of view. Therefore it is doubtful whether medians and centlies are of great value for the assessment of motor retardation in terms of neurological integrity. Also during their later development (when this book was written the youngest child was about 6 years old) none of them showed any neurological or mental disturbances, which would point at a cause for a retardation of motor development. Thus it can be contended that the quality of the developmental course rather than a strictly delineated time schedule has to be considered in order to evaluate the integrity of the nervous system.

## Reactions and responses

In this section a number of reactions and responses will be discussed which fulfil the criteria for group III. They are arranged in Table V, in subgroups composed for reasons of convenience (Pag. 42).

### Rooting reflexes

*Procedure:* Rooting was elicited according to the method described by Prechtl and Beintema (1964). During the first 4 or 5 months of life, the infant was usually in supine position, subsequently it was seated on the mother's lap. State 3 or 4.
All the infants were examined about half an hour before feeding; in this way the differential effect of the feeding condition was eliminated as much as possible.

*Recording:*

0. No turning of the head in the direction of the stimulated area.
1. Slight reaction to lateral stimulation, no reaction to stimulation of upper or lower lip.
2. Slight reaction to stimulation of all four areas.
3. Evident reaction to lateral stimulation, but slight reaction to stimulation of upper and lower lip.
4. Evident turning of the head towards the stimulated side both in horizontal and vertical direction.

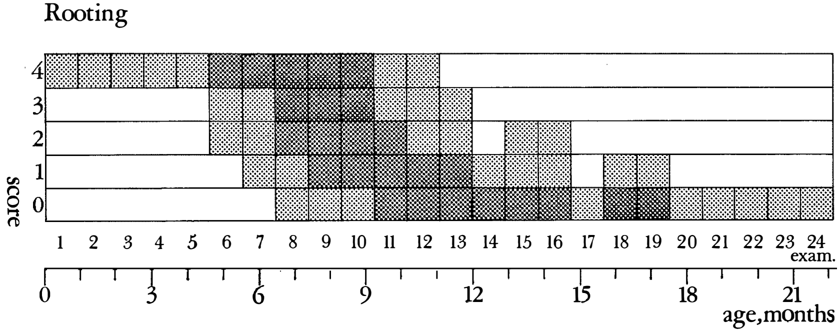



Fig. 26

The prediction band for rooting is presented in figure 26. An evident rooting response was observed in more than 80% of the infants until the seventh assessment. More than 80% of the infants showed a negative response only after about half a year. The variation range was large and many inconsistencies occurred (see appendix J) without evident sex differences. There were no differences between boys and girls with regard to the moment of the first change, the final change or the length of the developmental range.
A negative relationship with a low correlation coefficient ($r = -.438$, $p < 0.01$), was found between the moment of the first change and the length of the developmental range. This means that in infants who showed an early first change, a protracted developmental range could still be found. The close relationship between the final change and the developmental range ($r = .824$) suggests also a preprogramming of the dissolution of the response. The number of inconsistencies was related to the length of the developmental range ($r = .557$, $p < 0.01$).

The large number of inconsistencies is in accordance with Ingram's opinion that in healthy infants both inter- and intra-individually a great variation is found with regard to the feeding reflexes (Ingram, 1962). This was already observed by Prechtl (1958) in his study on the head turning response of the human baby and interpreted as dependent on the internal state of the infant. General motility, metabolic rate (hunger or satiation), drowsiness, sleep, defaecation or micturition etc. may largely influence the response. He described habituation after repetitive stimulation and a reappearance of the response due to a "central reset" when the stimulation is continued. This may be applied to other reflexes and responses as well; it leads to the variability which can be considered as a characteristic property of the healthy nervous system.
Relationships with parameters of other items were virtually absent. The spectacular difference with Paine's (1960) opinion that until three or four months after birth the rooting response can only be obtained in the infant when awake may be explained by the fact that in the present study the rooting response was elicited shortly before feeding time, while Paine does not give any information about his standardization.
In the present study the response was elicited by gently stroking the transitional area between lip mucosa and surrounding skin, and the skin of lips and cheek just aside of the lip mucosa. A consistent difference between the results of those two modes of elicitation was not observed. During the first assessment in the newborn period most infants reacted to both stimulations with rapid and often overshooting turning movements of the head into the direction of the stimulation, while during subsequent examinations on both types of stimulation the head movements were found to be slower and more adequate.
As Prechtl (1958) has show, two types of reactions can be distinguished in this connection; the "side to side movements", occurring in response to tactile stimulation near the mouth, i.e. on the skin of the

cheek or lips (also at a larger distance) and even occurring spontaneously without stimulation, and the "directed head turning response" which develops during the first few weeks after birth and which only can be elicited from the immediate adjacent area of the lips. According to Prechtl the "rhythmical searching", manifesting itself in side to side movements, disappears and is replaced by the "directed head turning response".

Sucking responses were not analysed, as the reactions to insertion of a stimulating finger or nipple were too variable and heterogeneous. Many infants bit or sucked inconsistenly. Especially during the teething-period, which was very variable in occurrence, sucking responses could hardly be obtained in a standardized way. It is posible that the examination time juist before feeding, when the infants were hungry, was particularly unfavourable for the examination of sucking responses.

**Asymmetric tonic neck responses**

*Procedure:* The infant was put on a flat surface in supine position. The examiner rotated the infant's head to one side and kept it in this position for about 15 seconds. The type of movement and the resulting posture of the arms and legs were observed. Extension of the arm and/or leg on the side towards which the face was turned was considered as a positive response.

In the connotation of this study this response was called the *imposed asymmetric tonic neck reaction.* Comparable responses resulting from a spontaneous turning of the head to one side or the other, were called *spontaneous asymmetric tonic neck reactions* and recorded separately.

*Recording:*

0. No consistent movement pattern of arm and/or leg on rotation of the head.
1. Slow and variable response, consistently replicable.
2. Immediate and consistent response, present in arm and leg, though easily counteracted by spontaneous motility.

The assessment during which a positive response was obtained for the first time, was regarded as the moment of onset of the first change. This could be a score 1 or a score 2. The final change was regarded to have taken place when the response had disappeared, i.e. a score 0 was obtained.

The prediction bands for the asymmetric tonic neck reaction, imposed and observed during spontaneous motility, are presented in figures 27 and 28 respectively. More than 80% of the infants did not show any asymmetric tonic neck reaction during the first assessment. During the second assessment, more than 80% of the infants showed a positive

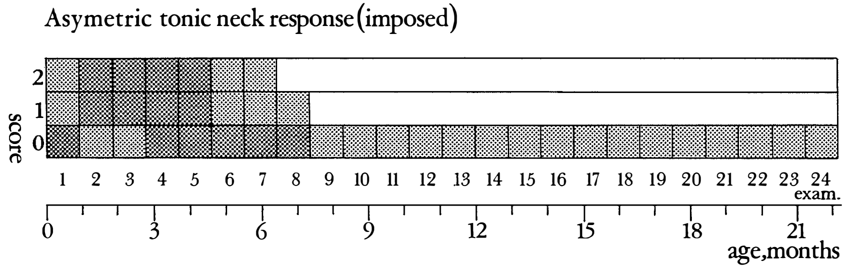


Fig. 27

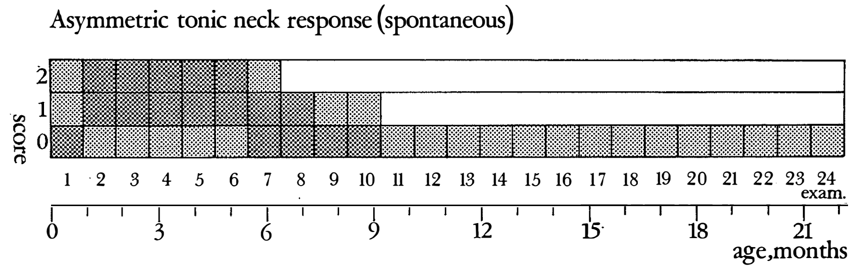


Fig. 28

reaction. As for the spontaneous asymmetric tonic neck reaction, this was the case until the sixth assessment. Only 10% of the infants did not show any spontaneous asymmetric tonic neck response during development. About half of the infants obtained a score 2 at some moment during the first months of life.

The results of the imposed asymmetric tonic neck reaction were largely dependent on the infant's amount of activity. Only at the second and third assessment a positive reaction could be obtained in more than 80% of the infants. The decrease of this percentage could be ascribed to the infant's increasing active resistance to manipulation when growing older; this may also explain the large variability of the scores from the fourth assessment onwards. In a small minority of easy going infants a positive response could be obtained until the eighth assessment, i.e. until about 32 weeks of age. Spontaneous asymmetric tonic neck patterns occurred during a much longer period of time.
One third of the infants showed inconsistencies during the elicitation of the asymmetric tonic neck reaction. It is not surprising that inconsistencies occurred more frequently in the asymmetric tonic neck reactions observed during spontaneous motility. There were no differences between boys and girls. For the imposed and the spontaneous asymmetric tonic neck reaction a significant relationship with a negative correlation coefficient was found between the moment of the first change and the length of the developmental range ($r = —.520$ and $r = —.510$, $p < 0.01$, respectively).

The relationship between the dissolution of the spontaneous asymmetric tonic neck response and the onset of development of coordination of the upper extremities has been discussed above (page 58).

At first glance there seems to be a resemblance between the asymmetric tonic neck reaction observed in infants and the asymmetric tonic neck reflex as described in neurological patients and as known from animal experiments. Nevertheless Magnus and De Kleyn did not consider the infantile reaction as an equivalent of the pathological reaction (cited by Vassella and Karlsson, 1962). Vassella and Karlsson studied the response in the newborn period; taking into account the criteria for the specificity of the motor pattern and its consistent occurrence, they concluded that a true asymmetric tonic neck reflex such as described by Magnus and De Kleyn occurred only in about 8% of newborns. Gesell reported that the response is frequently found between the second and fourth month of life, but he did not report his methods of standardization and operationalization (Gesell and Amatruda (1947)). Paine (1964) paid attention to the variability of the response; in his opinion the response occurs inconsistently in the newborn period and reaches its peak frequency during the second, third and fourth months of life. Yet it is not clear which type of asymmetric neck reaction he had in mind. As he talked about spontaneous postures in the crib, it may be assumed that he meant the spontaneous asymmetric tonic neck response only.

In the present group of low risk infants a stereotyped response which cannot be counteracted by spontaneous motiliy and such as is observed in pathological conditions, was not found. The asymmetric tonic neck reaction found in these infants, was characterized by a large variability of the pattern and by an interference by spontaneous motility. This illustrates again the fact that variability and stereotypy can be considered as the characteristics which determine the significance of a response.

**Palmar grasp reflex**

*Procedure:* The infant was in supine position with his head centered. The examiner inserted his index finger into the palm of the infant, starting from the ulnar side of the hand. The response consisted of a tonic flexion of the fingers around the stimulating finger (see also Prechtl and Beintema, 1964). State 3 or 4.

*Recording:*

.0 No immediate synchronous tonic flexion of the infant's fingers around the stimulating finger. Exploratory movements of hand and fingers around the stimulus eventually resulting in grasping were also scored under this heading.

1. A weak, often not long sustained, tonic flexion of the infant's fingers around the stimulating finger. Repeated flexion/extension movements of the infant's fingers around the stimulating finger were also scored.
2. Evident, sustained tonic flexion of the infant's fingers around the stimulus.

The palmar grasp reflex consists of a tactile and a proprioceptive afferent part. It may be assumed that in scores 1 and 2 both afferent pathways are in full operation. It is likely that in score 0 the proprioceptive part is operative to a lesser degree. Increased pressure on the infant's palm, for instance during traction, did not intensify the response as happened in the case of scores 1 and 2. On the contrary mere tactile stimulation was often followed by some variable flexion of the fingers and/or exploratory flexion/extension movements of the fingers or even withdrawal. It was concluded that tactile stimulation did not result in a palmar grasp reflex but in voluntary behaviour. For this reason score 0 was considered to reflect absence of the reflex for both types of afferent input.

A score 1 was regarded as reflecting the first change of the response, while a score 0 denotates the dissolution of the palmar grasp reflex (final change).

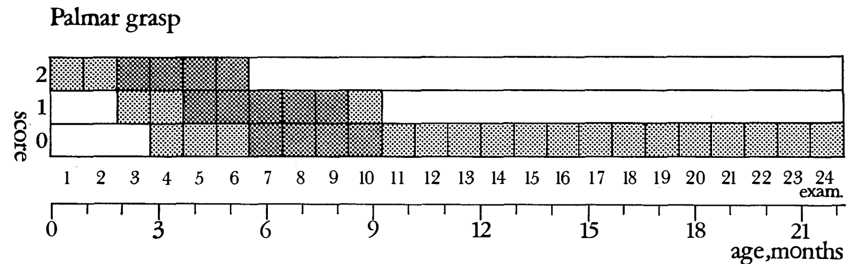


Fig. 29

The prediction band of the developmental course of the palmar grasp reflex is presented in figure 29. In 80% of the infants the developmental range was found between 16 and 40 weeks of age. At the sixth assessment, i.e. at about 24 weeks of age 24% of the infants still obtained a score 2. From the seventh assessment onwards the number of negative scores increased rapidly.
Inconsistencies were found in 24% of the infants, without differences between boys and girls. Boys and girls did not differ with respect to the time of onset of the first change, the final change, or the length of the developmental range.
A negative relationship was found, though with a low correlation coefficient ($r = -.436, p < 0.01$) between the first change and the developmental range. At the same time a relationship between the first and the final change was observed, also with a low correlation coeffcient ($r = .375$, $p < 0.01$). There was a closer relationship between the developmental range and the final change of the palmar grasp reflex ($r = .665$, $p < 0.01$). It is not easy to explain this pattern of relationships. In some infants the moment of the complete dissolution of the reflex seems to be more or less fixed, irrespective of the moment of the first appearance of the development; this is reflected by the relationships between the

developmental range and the final first changes respectively. In other infants the time needed for the dissolution of the reflex seems to be preprogrammed, as illustrated by the relationship between the first and final changes. This combination of relationships illustrates the problems of operationalization of the final change of the response, in particular. As was implied in the description of the scores, with increasing age and development it becomes increasingly difficult to distinguish the response from voluntary grasping behaviour. Thus the amount of active voluntary behaviour, which varies intra- and inter-individually may affect the developmental course of the response differentially.

In the paragraph dealing with the developmental course of voluntary grasping, its relationship with the palmar grasp reflex has been discussed. Also the relationships with walking and standing have been mentioned before.

The palmar grasp reflex illustrates the confusion which may arise if definitions and operationalizations are not congruent.
Halverson (1940) distinguished two aspects of the reflex, which was confirmed by André-Thomas and St. Anne Dargassies (1952) who mentioned an exteroceptive and a tonic proprioceptive reflex as two separate motor phenomena. The exteroceptive reflex would disappear during the first months of life, while the proprioceptive reflex would persist until the end of the first year. Koupernik and Dailly are of the same opinion (Koupernik and Dailly, 1968). Poeck (1968) stated that the palmar grasp reflex can be regarded as comparable to the grasping reflex found in adult braindamaged patients. His argumentation is based on the finding that the stimulus quality is rather unspecific as in the case of adult patients; he observed merely differences in latency time in connection with various types of stimulations. Twitchell (1970) described the development of grasping and the palmar grasp reflex completely in terms derived from adult pathology. In his view the infant's grasping behaviour consists of a combination of reflexes which can be elicited from various areas of the hands and fingers. To account for these reflexes he draws upon Denny-Brown's work which deals with neurologically impaired adults and laboratory experiments with (adult) monkeys (Seyffarth and Denny-Brown (1948)). In Twitchell's description of what he calls the "palmar grasp reflex" one does not recognize the palmar grasp reflex as shown in Prechtl's film (1953) and described by Prechtl and Beintema (1964). Here the palmar grasp reflex is a motor phenomenon in which the whole hand and arm participate and which is evidently based on a complex integration of brain mechanisms (including postural mechanisms and state organization), to a larger degree than would be congruous with mere hand- and finger-reflexes. Twitchell's discussion of the development of grasping and grasping reflexes is an example of the difficulties which arise if one does not consider the specific properties of the infant's nervous system, which is fundamentally different from the nervous system of the (braininjured) adult.

When the palmar grasp reflex is seen as an infantile phenomenon, it is extremely difficult to make a clear distinction between the various causal mechanisms; one must confine oneself to the appreciation of the clinical response as such. During development, the brain mechanisms which are responsible for the reaction gradually become incorporated in qualitatively different mechanisms, which in their turn are reflected by the development of the infants' abilities. A distinction of mechanisms made on the basis of animal experiments and findings in adult patients is artificial and even fallacious. In these instances qualitatively different mechanisms are operative, on the one hand due to the different degree of maturation of the brain, and on the other hand to the damage. A healthy infant is never comparable with a brain-damaged adult.
In the present study a pragmatic operationalization of the palmar grasp reflex was applied and a specific developmental course could be defined which permits a clinical appreciation of deviations.

**Reaction to push against the shoulder during sitting**

*Procedure:* This test assesses balance during sitting position. The examiner gave a gentle sideward push against the infant's shoulder while he was sitting free. The ability of the infant to remain in sitting position was recorded. State 3 or 4.

*Recording:*

0. The infant was not able to sit unsupported.
1. The infant fell aside if pushed against the shoulder.
2. The infant placed his arms sidewards in order to support himself but he did not succeed and toppled over.
3. The infant remained sitting when pushed against the shoulder, effectively using his arm for support.

Scores 1 and 3 were regarded to reflect the first change and the final change respectively.

Reaction to push against shoulder during sitting

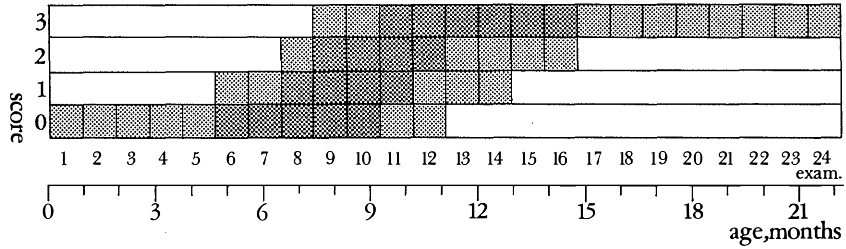



Fig. 30

The prediction band for this balance behaviour is presented in figure 30. A score 3 can be regarded as reflecting well developed balance during sitting. This score was obtained by about half of the infants at about 45 weeks of age; more than 80% of the infants showed a good balance only at the age of one year. One infant did not show any supporting reaction of the arm when falling sidewards before the 16th assessment, i.e. at the age of about 64 weeks. There were only a few inconsistencies in the responses of this test. Differences between boys and girls with respect to the moments of the first changes, the final changes, the lengths of the developmental ranges and the number of inconsistencies were not found. A relationship was found between the moment of the final change and the length of the developmental range ($r = .628$, $p < 0.01$); a negative relationship was found between the moment of the first change and the length of the developmental range ($r = -.531$, $p < 0.01$). This suggests that the moment of stabilization is more or less fixed in time. It reflects the time course during which the integration of brain mechanisms, needed for this motor function (cerebellar and brain stem differentiation and integration) takes place. André-Thomas considered the response mainly as an acquired reaction achieved after repeatedly falling sidewards and resulting from the frequent use of the arms for support in other positions as well (André-Thomas and St. Anne Dargassies, 1952).

As the response to push against the shoulder was tested only when the infants were able to sit free for some seconds, it cannot be considered as identical with the lateral supporting reaction. The latter is defined as a supporting extension of the arm and a sideward placing of the outstretched hand when the infant is pushed sidewards, irrespective of his ability to sit, and various authors report it as occurring earlier than the test described in this section.

Comparison of the prediction bands for the duration of sitting and the response to push against the shoulder (fig. 20 and 30) shows a considerable conformity of shape and length. Indeed most of the infants who had achieved the ability to sit for just a few seconds, tended to topple over without using hands or arms for support when pushed against the shoulder, while parallel to the increase of duration of sitting the response to push against the shoulder improved. Thus one might say that the present test indicates the quality of sitting in terms of balance, rather than dealing with a lateral supporting reaction which might precede the ability to sit unsupported, and which can be regarded as reflecting only one constituent part of sitting balance.

The relationships between this balance reaction and the development of observed or induced motor activity such as sitting, rolling, standing, walking and behaviour in prone position, have already been discussed.

There was a close relationship with the other balance reaction during sitting, i.e. the ability to follow an object with eyes, head and trunk (r's ranging from .577 to .628, $p < 0.01$).

**Following of an object with the eyes and rotation of the head and trunk when sitting**

*Procedure:* The examiner moved an interesting toy around the sitting infant, encouraging him to look at it. The angle over which the infant could rotate without losing balance was recorded.
State 3 or 4.

*Recording:*

0. The infant was not able to sit without support.
1. The infant was not able to watch the object without losing balance.
2. The infant was able to watch the object over c. 30 degrees to both sides.
3. The infant was able to watch the object over c. 60 degrees to both sides.
4. The infant was able to watch the object over c. 90 degrees to both sides.

Scores 2 and 4 were considered to reflect the moments of the first and final changes respectively.

Visual following of an object with head and trunk, sitting

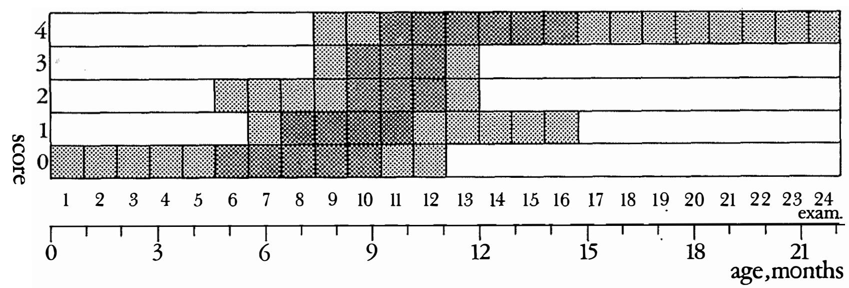



Fig. 31

The prediction band for this ability is presented in figure 31. It is evident that the ability to rotate without loosing balance develops rapidly. One infant was not able to watch the object without losing balance until the sixteenth assessment, i.e. until about 64 weeks of age. This same infant was also not able to keep his balance after being pushed against the shoulder. Obviously the development of balance was retarded in this infant. A good balance during sitting was found in more than 80% of the infants at the age of one year. This corroborates the finding that in the majority of the infants of the present group stable and mature sitting had developed at about one year of age. Still the variation range was large and amounted to about six months.

Inconsistencies were observed in a minority of the infants, in the girls slightly more often than in the boys. This difference was not statistically significant (Mann-Whitney U Test), neither were there significant differences between boys and girls as for the moment of the first change, the final change or the length of the developmental range.

There was a negative relationship between the moment of the first change and the length of the developmental range ($r = -.565$, $p < 0.01$), as was the case with the item response to push against the shoulder. There was a significant relationship between the moments of the first and final changes ($r = .591$, $p < 0.01$) which was not found in the case of item response to push against the shoulder. This means that to a certain degree the amount of time needed for the development of this motor ability is fixed. The relationships with other items have been discussed before.

**Optical placing reaction of the hands**

*Procedure:* The infant was kept in prone suspension and suddenly lowered towards a flat surface. The movements of arms and hands were recorded. State 3 or 4.
The response consisted of a forward extension of the arms and opening and dorsiflexion of the hands on approaching the surface.

*Recording:*

0. No forward extension of the arms and/or opening of the hands.
1. Forward extension of the arms; opening of the hands and dorsiflexion of the wrists occurred only on touching the surface.
2. Forward extension of the arms and opening and dorsiflexion of the hands during the downward movement.

Scores 1 and 2 were regarded to reflect the moments of first and final changes respectively.

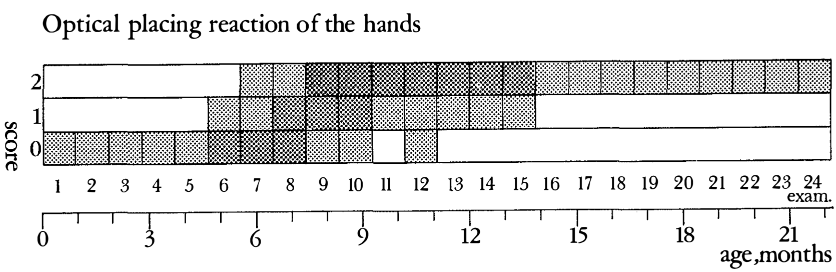



Fig. 32

The prediction band for the optical placing reaction of the hands is presented in figure 32. The reaction showed a rapid developmental course from the eighth assessment onwards; about half of the infants displayed a weak response at the eighth assessment and two thirds of them showed a full response at the tenth assessment, i.e. at about 40 weeks of age. The variation range for the total group was large; it depended on a small minority of infants who, with regard to the development of this response, were very early and very late respectively. Inconsistencies occurred in a minority of infants. There were no statistically significant differences between boys and girls with respect to the moments of the first changes, the final changes, the lengths of the developmental ranges or the occurrence of inconsistencies. There was no relationship between the moment of the first change and the length

of the developmental range; the moment of the first change does not predict the amount of time needed to develop a mature response.
Still, the final change and the developmental range were closely related ($r = .745$). This implies that the moment of final stabilization is rather fixed in time, which may reflect the sensorimotor maturation needed for visual placing. André-Thomas considered the response as an acquired reaction and even postulated it as a manifestation of mental development (André-Thomas and Saint Anne Dargassies, 1952), which can never be explained by the present findings.
There was a statistically significant relationship ($r = .483$, $p < 0.01$) between the full establishment of the optical placing reaction of the hands and the first appearance of the parachute reaction of the hands. There was no significant relationship between the first changes of both reactions, while the correlation coefficient for the relation between the final changes was also .483. With a view to the similarity of the two reaction types a relation could be expected; still the correlation coefficients are low, so that the response of the one reaction cannot be regarded as indicative or predictive of the response of the other (see also the next section).

**Parachute reaction of arms and hands in prone suspension**

*Procedure:* The infant held in prone suspension was suddenly dropped a few centimeters, visual control not being permitted. As blindfolding the infants would imply a disturbance of an adequate behavioural state, elimination of visual control was brought about by drawing the infant's attention to an interesting toy, displayed in front and a little above him. In this way it was possible to standardize the head position and consequently the influence of the position of the head on the muscle tone activity of the arms. State 3 or 4. A positive response consisted of a forward extension of the arms and dorsiflexion and opening of the hands during the movement.

*Recording:*
0. No forward extension of the arm and/or opening of the hands.
1. Slight forward extension of the arms, occasionally followed by opening of the hands.
2. Evident forward extension of the arms, accompanied by opening of the hands.

Scores 1 and 2 were regarded to reflect the first and final changes respectively.

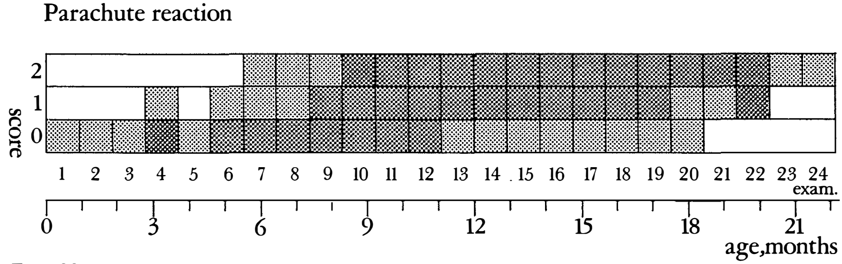



Fig. 33

The prediction band for the parachute reaction is presented in figure 33. Comparison with figure 32 shows a later appearance and a more protracted developmental course as the main differences between the parachute reaction and optical placing of the hands. The irregular shape of the end of the prediction band is caused by the decrease of the number of infants in the group at the end of the period of study. In many infants one or more inconsistencies were found; in the girls slightly more often than in the boys. Statistically this difference reached a 5% level of confidence (Mann-Whitney U test). This was also the case with the length of the developmental range, which was slightly longer in the girls. A statistically significant relationship was found between the final change and the developmental range ($r = .671$, $p < 0.01$) and between the moments of first and final changes ($r = .621$, $p < 0.01$). Thus one cannot assume either a fixed end of the developmental course or a fixed amount of time needed for the development of this item, as both may occur in each individual infant. There was a significant relationship between the length of the developmental range and the number of inconsistencies ($r = .648$, $p < 0.01$) (Spearman Rank Correlation), which may reflect the problem of operationalization and standardization; it might also be considered as an illustration of the strain on the nervous system when this motor organization develops, i.e. when neuronal responses to a particular stimulus are integrated into one recognizable and consistent pattern. The main difference between the elicitation of the optical placing reaction and the parachute reaction as defined in the present study was the presence of visual control in the former. The steering influence of visual control appears to affect the occurrence of arm extension during downward movement in prone suspension considerably and illustrates the reinforcing effect of visual on vestibular input. Paine (1960) states that the parachute reaction is present when a baby older than eight or nine months is suddenly dropped towards a flat surface. The mentioning of the surface, together with an illustrating photograph in his paper, shows that he deals with the optical placing reaction of the hands; if this is right the results of the present study are in accordance with his findings.

**Optical placing reaction of the feet**

*Procedure:* The examiner kept the infant under the shoulders in vertical suspension and moved him towards a flat surface. The response consisted of an extension of the legs on approach of the surface. State 3 or 4.

*Recording:*

0. No extension of the legs on approach of the surface.
1. Slight extension of the legs.
2. Evident extension of the legs, anticipating placing of the feet.

Scores 1 and 2 were considered to reflect first and final changes respectively.

Optical placing reaction of the feet

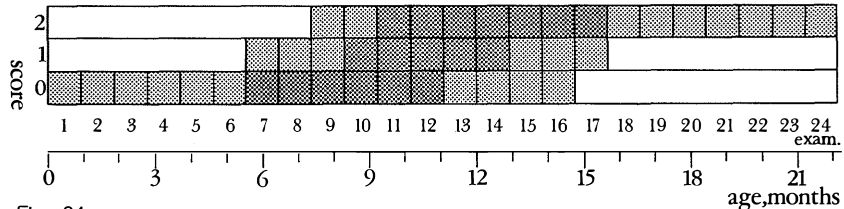



Fig. 34

The prediction band for this response is presented in figure 34. Although some infants already started to show an evident extension of the legs at about 40 weeks, half of them showed a complete response at about one year of age; in more than 80% of the infants the final change took place at about 60 weeks of age. A comparison of this prediction band with that for the posture of the legs in vertical suspension (fig. 11) and with the prediction band for the development of standing up (fig. 24), shows that the first changes of the optical placing reaction of the feet and of standing up occur in the same period when predominantly symmetrical motility of the legs in vertical suspension is found. In all these instances symmetrical motor patterns are involved. This illustrates a typical developmental process of the nervous system in which, in voluntary motor behaviour, infantile motor patterns are integrated.

Inconsistencies occurred in one third of the infants, without an evident sex difference. Neither were evident sex differences observed with respect to the moments of the first changes, final changes or lengths of developmental ranges. There was a close relationship between the moments of the first and the final change ($r = .777$), while the relationship between the moment of the final change and the length of the developmental range was appreciably lower, though still significant ($r = .505$, $p < 0.01$). These relationships suggest that the amount of time needed for the development of this reaction is fixed, and that the moment of final stabilization can be fixed in time as well.

The length of the developmental range and the occurrence of inconsistencies were also related ($r = .559$, $p < 0.01$). The relationships with parameters of other items have already been discussed in previous sections.

**Footsole response**

*Procedure:* The footsole response was elicited according to Prechtl and Beintema (1964). The infant's hip, knee and foot were kept in a semiflexed position and with his thumbnail the examiner scratched from the toes heelwards along the lateral side of the sole of the foot. This particular direction of the stimulation is necessary in order to avoid the elicitation of a plantar grasp reflex. Especially in older infants it was often difficult to avoid a withdrawal response. For this reason the stimulus intensity was varied interindividually. The movements of the big toe and the small toes as a reaction to the stimulation were recorded separately. The test was carried out five times consecutively and the final score was based on at least three comparable movements of the toes. State 3 or 4.

*Recording:*

0. No visible movement of the big toe or the small toes, or alternating dorsi- and plantar-flexion of the big toe or small toes. At the end of the follow-up a consistent and sustained plantar flexion of the big toe or the small toes occurred only in a minority of the infants. If present it was also scored 0.
1. Weak, often not long sustained, dorsiflexion of the big toe and fanning of the small toes.
2. Evident, sustained dorsiflexion of the big toe and fanning of the small toes.

A score 1 was regarded as the first change of the response and a score 0 as the final change.

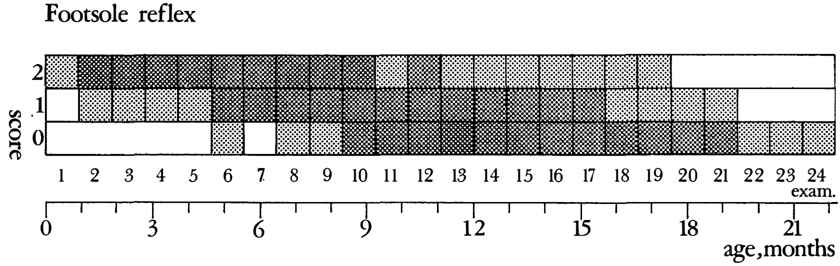



Fig. 35

A prediction band for the footsole response of the big toe is presented in figure 35. It shows that the development of the footsole response is rather protracted. The variation range was large, though more than 90% of the infants showed an evident and sustained dorsiflexion of the big toe until the fifth assessment. In about one third of the infants this was still the case at the age of 40 weeks (10th assessment). At the same age 40% of the infants showed an unequivocal response (score 0). The irregular shape of the prediction band and the full range demonstrate the occurrence of inconsistencies. The total number of inconsistencies was 79, distributed over 39 infants; there was no difference between boys and girls. The small toes showed an evident and sustained fanning and dorsiflexion in more than 80% of the infants until the ninth assessment, i.e. until about 36 weeks. 24% of the infants showed this type of response until the age of one year. A score 1 for the big toe as well as for the small toes could be found during the whole period of infancy.

It was observed that a consensual reaction, i.e. an identical and simultaneous movement pattern of the toes of the opposite foot, occurred in more than 80% of the infants between five and sixteen weeks of age. Subsequently a consensual reaction was found in a rapidly decreasing percentage of the infants, but it could be observed in a small minority until the end of the follow-up study.

Attention should be paid to the position of the head during the elicitation of the footsole response. In more than half of the infants the dorsiflexion was weaker on the side towards which the face was turned at any time between the second and the seventh assessment. The influence exerted by the position of the head was strongest at the age of about 16 weeks, when this phenomenon was observed in three quarters of the infants. It may be explained by the effect of the asymmetric tonic neck reaction (Walshe '23).
A consistent asymmetrical pattern, mainly with regard to the moment of disappearance of an evident dorsiflexion such as reported by Babkin (1969), was not found.
There were no statistically significant differences between boys and girls, although in the girls the mean length of the developmental range was slightly more protracted than in the boys. This difference did not reach statistical significance. The time of onset of the first change was negatively related to the length of the developmental range ($r = -.551$, $p < 0.01$), while the final change and the developmental range were positively related ($r = .679$). This may be explained by the fact that in healthy infants, when being handled, voluntary activity will be provoked, so that the stimulus may not only result in a footsole response but in other movements also, which, dependent on their intensity, may blur the actual response.

A relationship was found between the time of onset of the final change and the number of inconsistencies ($r = .542$, $p < 0.01$). This illustrates the problem of defining the moment of the last change unequivocally. There was no statistically significant relationship between the moments of the first changes of the footsole reflex and standing or walking respectively, or between the lengths of the developmental ranges of these three items.

There was a significant relationship between the moment of the last change of the footsole response and standing free, though with a low correlation coefficient ($r = .409$, $p < 0.01$) while the relationship with walking free had a correlation coefficient of $r = .376$ ($p < 0.01$).

Although these correlation coefficients signal statistical significance they are so low that any individual predictive validity, which may be of clinical value is precluded.
The relationships of the final change of the footsole response with the onset of the development of standing up and walking have been discussed in the sections dealing with these two items.
Although phenotypically the dorsiflexion type footsole response in infancy resembles the so-called Babinski reflex, the infantile response has a different clinical significance. In a clinical neurological connotation the Babinski reflex consists of an isolated dorsiflexion of the big toe, caused mainly by supranuclear lesions of the Central Nervous System. In the present group isolated dorsiflexion of the big toe occur-

red rarely and inconsistently. Clinically, fanning of the small toes, usually coupled with a dorsiflexion of the big toes and comparable with the fanning and dorsiflexion of the small toes in infancy, is known as the Babinski II or Signe de l'éventail. Babinski regarded this movement pattern of the small toes as being a sign of probability in favour of a disturbance of the pyramidal system (Babinski 1903, reprinted by Wilkins and Brody, 1967) and belonging to the original pattern, which consisted of toe movements, knee flexion and hip flexion on stimulation of the footsole. It would occur as a neurological sign of a more extensive lesion of the brain. This is doubted by Grimby (1963b), who assumes that "the individual variations found in the pathological material are too manifold to be ascribed solely to lesions of varying degrees of severity". He emphasizes that also in healthy individuals Babinski type responses may be found, which is in accordance with the findings published by Madonick (1960) who reported an incidence of 4.3% Babinski responses in a group of 2500 non-neurological (adult) subjects. Babinski himself described an extension of the big toe and abduction of the toes in newborns and recognized its different clinical significance, compared with the response as observed in adults, because in his opinion it reflected the immaturity of the pyramidal tract. Still, he used this finding to support his idea that "the toe phenomenon is related to a disorder of the pyramidal system". (Babinski, 1903, reprinted by Wilkins and Brody, 1967). Brain and Wilkinson (1959), in their extensive review of the Babinski reflex, pointed out that it is highly improbable that a pathological and neurological sign would exist in healthy infants. Generally speaking, a pathological sign is characterized by a high amount of stereotypy, while variability, including inconsistency is characteristic of a healthy nervous system.
With a view to the large amount of inconsistencies and variability during the developmental course of the footsole response during infancy, its must be emphasized that clinically the infantile footsole response cannot be regarded as a Babinski in the adult connotation.

As among others Kugelberg et al (1969), Grimby (1963a,b) and Gassel (1970) have pointed out, the phenotype of the toe movement (the dorsiflexion and fanning on the one hand and plantar flexion on the other hand) results from a shifting of balance between toe extensors and toe flexors due to changing suprasegmental influences. In a healthy individual the suprasegmental organization generally promotes a plantar flexion as a result of stimulation of the sole of the foot, especially when this stimulation is carried out at the lateral side of the sole (as Kugelberg et al. (1960) and Grimby (1963a) have shown, the movement pattern of the big toe is largely dependent on the stimulated side of the sole). When the susprasegmental influences are affected by a neurological disease, a dorsiflexion of the big toe may be promoted. During early infancy dorsiflexion of the big toe appears to be the usual (segmental) response to stimulation of the sole of the foot; the transition to the flexor type responses (plantar flexion) or a perfect balance between extensor and flexor activity (no visible movements of the toes, i.e. "indifferent" reaction) reflects a modification of the suprasegmental influence on the spinal mechanism, resulting from the maturation of the cerebrospinal mechanisms. This process should not be confused with that of a modification of the suprasegmental influences the other way round (i.e. from plantar flexion to dorsiflexion) due to a disturbance of the cerebrospinal organization.

In clinical neurology many other modes of stimulation of the legs or even of the body may result in a dorsiflexion of the big toe. They are usually ascribed to an expansion of the reflexogenic area of the footsole response as such. During the first seven or eight months of infancy these responses can also be observed in infants as was stated by Brain and Wilkinson (1959). In the present study Oppenheim's response (rubbing the skin in a downward direction resulting in dorsiflexion of the big toe) occurred in more than 80% of the infants until about 32 weeks. The response was often weak and rather inconsistent. Chaddock's response (rubbing the skin around the external ankle resulting in dorsiflexion of the big toe) occurred in about 75% of the infants until about 20 weeks of age; it could be elicited in about 25% of the infants until the age of about 50 weeks. Especially during the second half of the first year the response turned out to be increasingly inconsistent. In about half of the infants a gentle downwards stroking of the skin of the inner surface of the thigh resulted in an evident dorsiflexion of the big toe and a dorsiflexion of the small toes during the first 20 weeks. A weak non-sustained dorsiflexion occurred in a minority of infants until the end of the first year. Rossolimo's response (tapping the ball of the first toe resulting in fanning of the toes) was inconsistently present in about half of the infants during the first 20 weeks. Subsequently the frequency of the response decreased rapidly. Comparable results were found for the response of Mendel-Bechterew (gentle tapping on the cuboid bone of the foot resulting in fanning of the toes).

In alle these responses movements of the big toe were accompanied by movements of the small toes. The inconsistency and variability of the responses differentiate them spectacularly from the usually stereotyped pathological condition. One may agree with Holt's conclusion that an extensively enlarged reflexogenic area after the first half year, and a persistence of a dorsiflexion of the toes after the age of two years should be regarded as abnormal (Holt, 1961).

### Acoustical orienting

*Procedure:* While the infant was seated on the mother's lap, the examiner rang a small nursery bell behind the infant's head outside his visual field, on the left and right side consecutively. Orienting movements of the infant's head trying to localize the source of the sound, were recorded. State 3.

*Recording:*

0. Diffuse reaction of the infant without evident oriented movements of the head. Some horizontal movements could be observed.
1. Turning the head towards the side of the stimulation without immediate localization. The movement consisted of two clearly distinguishable parts: a lateral rotation of the head, followed by vertical or oblique searching movements of the head.
2. Immediate localization of the source of the sound in one smooth orienting movement.

Scores 1 and 2 were considered to reflect first and final changes respectively.

Acoustical orienting

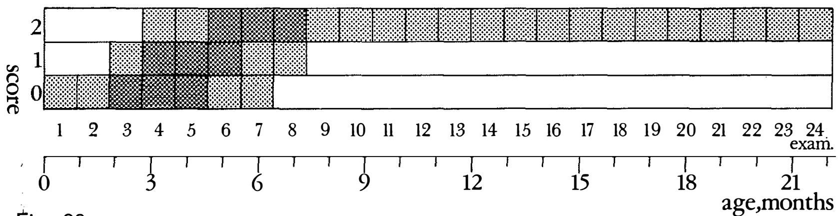



Fig. 36

The developmental course of acoustical orienting is presented in figure 36. The developmental course was rapid; 50% of the infants showed the onset of orienting at the age of about 20 weeks, while half of the infants showed adequate orienting at the age of 24 weeks; 96% of the infants localized the sound accurately at the age of about 32 weeks.

Inconsistencies hardly occurred. There were no diffenrences between boys and girls. The findings are in accordance with the data given by Koupernik and Dailly (1968) and by Murphy (1962). Accurate orienting to the left being preceded by orienting to the right, or vice versa as found by Murphy was not observed.
There was a low but significant relationship between the moments of the first and the final changes ($r = .399$, $p < 0.01$); the first change and the developmental range were also related (with a negative correlation coefficient: $r = -.395$, $p < 0.01$), while the closest relationship was found between the developmental range and the final change ($r = .685$). This set of relationships suggests that in the majority of infants the moment of stabilization of the response is more or less fixed, irrespective of the moment of the first developmental manifestation. In other infants it seems that it is the amount of time needed for the full development of acoustical orienting which is more or less fixed. Still, the low correlation-coefficients show that only a small proportion of the variance which may occur in the group ($r^2$) is explained by this relationship. Obviously the prediction of the developmental range of acoustical orienting solely on the basis of its first appearance is hardly feasible. Relations with parameters of other items were not found.

### The Moro reaction

*Procedure:*

The Moro reaction was elicited in three different ways: by headdrop, lift and hit on the surface, as described by Prechtl and Beintema (1964). Abduction and extension of the arms on the one hand, and flexion and adduction of the arms on the other hand, were scored separately for all the three modes of elicitation. State 3 or 4.

#### Headdrop method, abduction/extension

*Recording:*

0. No reaction.
1. Slight abduction/extension of the arms not surpassing 70° - 90° extension in the elbow joint and 45° abduction in the shoulder joint respectively.
2. Evident abduction/extension of the arms (more than 90° and 45° respectively).
3. Complete abduction/extension of the arms (a score 3 did not occur in this group of infants).

#### Headdrop method, adduction/flexion

*Recording:*

0. No reaction.
1. Slight adduction/flexion of the arms.
2. Evident adduction/flexion of the arms.
3. Full adduction/flexion of the arms (a score 3 did not occur in this group).

#### Lift method, abduction/extension

*Recording:*

0. No reaction.
1. Extension and spreading of the fingers only.
2. Slight abduction/extension of the arms, not exceeding 70° - 90° extension in the elbow joint and 45° abduction in the shoulder joint respectively.
3. Full abduction/extension of the arms (a score 3 did not occur in the group).

#### Lift method, adduction/flexion

*Recording:*

0. No reaction.
1. Slight adduction/flexion of the arms.
2. Evident adduction/flexion of the arms.
3. Complete adduction/flexion of the arms (a score 3 did not occur in this group).

**Hit method, abduction/extension**

*Recording:*

0. No reaction.
1. Slight abduction/extension of the arms, not exceeding 70° - 90° extension in the elbow joint and 45° abduction in the shoulder joint respectively.
2. Evident abduction/extension of the arms (more than 90° and 45° respectively).
3. Complete abduction/extension of the arms (a score 3 did not occur in this group of infants).

**Hit method, adduction/flexion**

*Recording:*

0. No reaction.
1. Slight adduction/flexion of the arms.
2. Evident adduction/flexion of the arms.
3. Fast and abrupt adduction/flexion of the arms.

The fast and abrupt adduction/flexion of the arms caused by a hit on the surface (score 3) was considered by McGraw (1943) as the mature phase of the Moro. The difference with the slight adduction/flexion of the arms (coded as 1), is expressed by the speed of the movements and the involvement of larger parts of the body in the movement pattern. The movement pattern, represented by a score 3, showed a very high speed compared with the gentle, smooth and rather slow adduction/flexion movement scored as 1; moreover in the fast and abrupt movement virtually the whole body was involved, showing a mass flexion pattern with flexion of the knees, hips, trunk, neck, forward movement of the shoulders etc. It closely resembled the fright reaction of the older child and the adult for instance to a sudden noise. As it was not found in all the infants and when found not consistently present it could not be utilized as the definite final change of the response. Its possible connection with the Moro reaction will be discussed later.

The scores defined as slight abduction/extension or adduction/flexion respectively were considered as the first changes. Absence of the response or, in the case of the adduction/flexion movements of the Moro-hit, the absence, or the presence of fast and abrupt adduction/flexion movements, was considered as the final change.

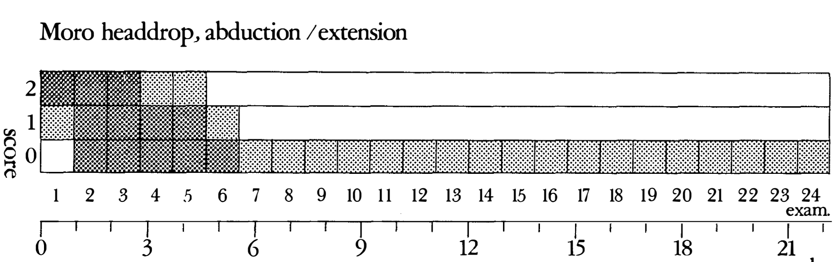



Fig. 37

Moro headdrop, adduction/flexion

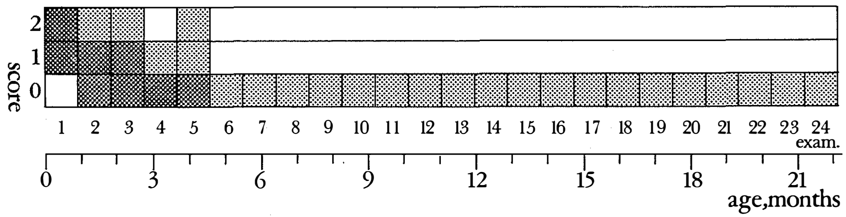



Fig. 38

Moro lift, abduction/extension

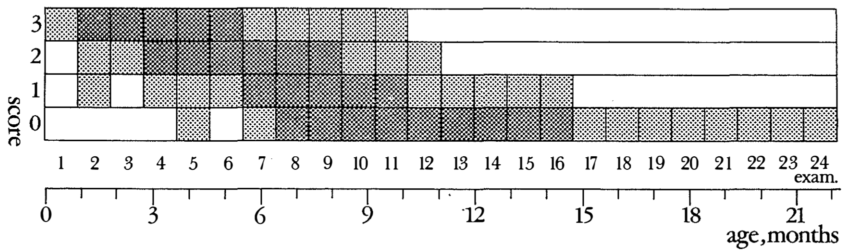



Fig. 39

Moro lift, adduction/flexion

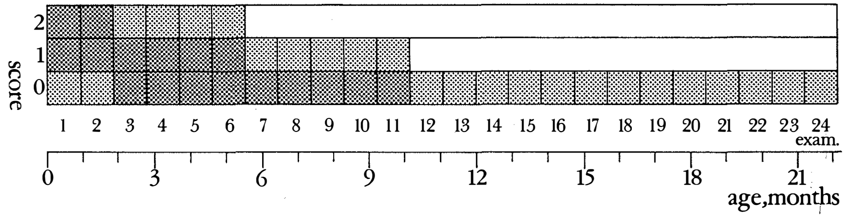



Fig. 40

Moro hit, abduction/extension

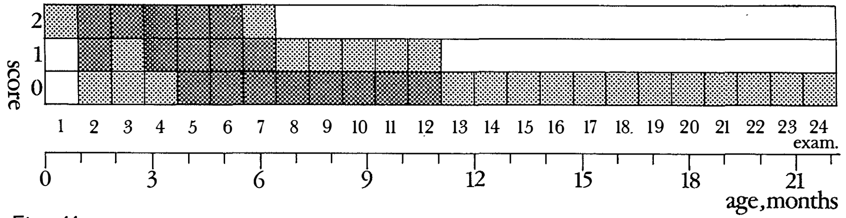



Fig. 41

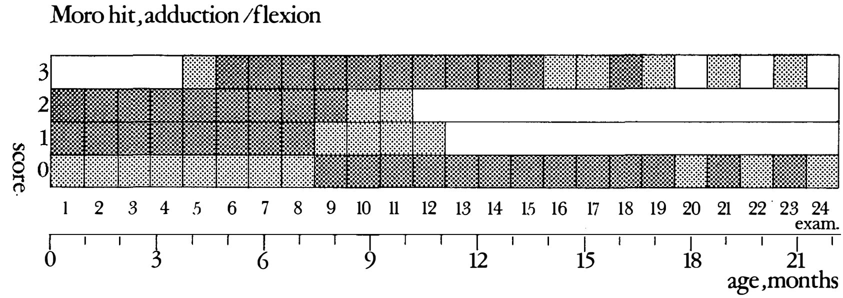



Fig. 42

The prediction bands for the Moro reactions are presented in figures 37 to 42. The headdrop-Moro has a rapid developmental course compared with the lift-Moro. In 78% of the infants it had disappeared at the age of about 20 weeks. This can be attributed to the fact that during the first months of life the infants became increasingly able to keep their neck muscles contracted, and prevent a backward drop of the head. Cowie's finding that in infants suffering from Down's disease the headdrop-Moro can be elicited much longer than in normal infants, can be ascribed to the hypotonia of the Down-patients which invalidates an efficient use of the neck muscles (Cowie, 1970; Touwen, 1971).

The prediction bands for the Moro elicited by the lift method show that the reaction may persist much longer than the headdrop method would suggest. This is true for the abduction/extension components, as well as for the adduction/flexion components (fig. 37-42). At the seventh assessment (28 weeks of age) an evident abduction/extension was still observed in 20% of the infants. At the ninth assessment (i.e. 8 weeks later) a sligth abduction/extension pattern was still found in 20% of the infants, while 12% of the infants showed slight but consistent finger-movements at the age of one year.

Adduction/flexion movements disappeared earlier, though twice as late as in the case of the headdrop-method.

As the prediction band for the abduction/extension movements of the Moro elicited by the hit method (fig. 41) shows, the abduction/extension movements of this type of Moro disappear earlier than those of the Moro-lift and later than those of the Moro-headdrop. At the eighth assessment (c. 33 weeks of age) 90% of the infants showed a negative response.

The prediction band for the adduction/flexion component of the Moro elicited by the hit-method (fig. 42) shows a different shape due to the occurrence of the fast adduction/flexion movements. About one third of the infants showed these fast movements at the sixth assessment (i.e. 25 weeks of age); the peak frequency occurred between the eighth and tenth assessment. Subsequently their frequency decreased slowly.

In the three types of elicitation of the Moro response the number of inconsistencies varied considerably. Their frequency was highest in the lift-Moro and the hit-Moro. The number of inconsistencies appeared to increase in accordance with the increase of the length of the developmental range (r's ranging from .371 to .594, $p < 0.01$).

In the case of the lift-Moro and the hit-Moro statistically significant relationships were found (with a negative correlation coefficient) between the first change and the developmental range (r = —.478 and —.668 respectively, $p < 0.01$). Moreover a significant relationship was found between the final change and the developmental range (r = .646 and .636, $p < 0.01$ respectively). This suggests that the moment of the final change is rather fixed in time.

There were no consistent differences between the boys and the girls, except for the occurrence of inconsistencies in the Moro elicited by the lift method; these were found more often in the boys than in the girls (Mann-Whitney U test, $p < 0.01$). This may be attributed to counteracting voluntary motor activity, often more prevalent in the boys than in the girls.
Systematic relationships between the three modes of elicitation of the Moro reaction were looked for. They were found only with respect to the final change. As these relationships varied in the case of boys and girls, they have to be dealt with separately.

In the girls there was a significant relationship between the abduction/extension components of the Moro elicited by the lift method and those of the hit method (r = .591, $p < 0.01$). They also showed a significant relationship between the adduction/flexion components of the Moro elicited by the headdrop method and hit method and those of the lift method and hit method (r = .569 r = .906 respectively). Both boys and girls showed a significant relationship between the adduction/flexion component of the Moro elicited by the headdrop method and that of the lift method (r = .564 and r = .742 respectively).

Within one mode of elicitation, significant relationships were found between the abduction/extension component and adduction/flexion component with correlation-coefficients ranging from r = .508 to r = .914. Usually the correlation-coefficients were a little higher in the case of the girls, while in the case of the boys no relationship was found between the two patterns of the Moro elicited by the lift method.

No significant relationships were found between the first changes and the final changes of the various Moro-reactions. Neither were correlations found with any other item, except for an inexplicable set of negative correlations between the final change of the abduction/extension component of the Moro elicited by the headdrop method (which shows the shortest developmental course) and items dealing with sitting (see Appendix D).

On the basis of this pattern of relationships two main conclusions can be drawn. Firstly the development of the Moro reaction seems to be independent of the development of other items as represented in this study. This is demonstrated by the lack of relationships between the parameters of the Moro reaction, elicited by three methods, and the parameters of the other items which are used to inventory the neurological development in infancy.
Secondly the three types of the Moro reaction (headdrop, lift and hit on the surface) are not identical as far as their developmental course is concerned. This may imply that they are based on different brain mechanisms or that their afferent input is differential. The latter hypothesis seems more plausible as the phenotypical expression of the different components is similar in all the three methods of elicitation, with the exception of the fast and abrupt adduction/flexion pattern elicited by a hit on the surface which is qualitatively different and not found in all the infants.
Peiper's (1963) and André-Thomas' (André-Thomas and Hanon, 1947) opinions differ with regard to the causal mechanisms of the Moro. Peiper believes that the Moro can mainly be ascribed to a vestibular stimulation, while André-Thomas contends that a proprioceptive input from the neck joints is the main source. Experiments carried out by Prechtl (1965) favour Peiper's opinion. If one tries to elicit the Moro reaction by a "body-drop" while keeping the infant's head position unchanged (i.e. a reversal of the headdrop method) even in the newborn no Moro reaction occurs. A contradictory phenomenon was found by Karlsson (1962, cited by Prechtl, 1965), who observed an infant without labyrinths, still showing a complete Moro reaction; this can be explained by the argument that if vestibular afference is absent the neck propriocepsis "takes over".
Yet even this need not be necessary because in this case other receptive fields (e.g. tactile receptors) are stimulated beside the neck propriocepsis. The „body drop" applied to an infant with labyrinths does not result in a Moro reaction; in this case the labyrinths seem to be mainly reponsible for the reaction.
As the Moro reaction can be elicited by headdrop and lift method it seems obvious that the otoliths of the labyrinths are the main receptors. This view is supported by the results of the hit method. This stimulus seems to be mainly of a vibratory kind; it is registered by the otoliths and not by the semicircular canals. This notion is founded on the fact that hitting a ferro-concrete surface on which a baby is lying does not result in a Moro reaction while a hit on for instance a wooden surface does so. Vibration of wood can be induced rather easily, while vibration of a heavy ferro-concrete under-layer is practically impossible.
According to Parmelee (1964) the stimuli have a differential effect, involving various afferent pathways; he still does not share Peiper's or André-Thomas' views thoroughly. He states merely that the mode of elicitation determines to a large extent which afference is responsible for the resulting motor patterns.

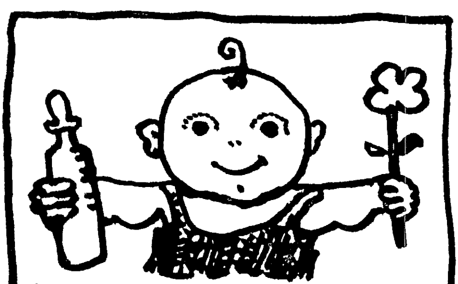
It is also contended frequently (for instance Paine, 1960; Koupernik and Dailly, 1968) that the different modes of elicitation of the Moro reaction merely vary the intensity of the response. This reasoning seems to be too simplistic. It is worthwhile again to pay attention to Cowie's (1970) remarks on the dissolution of the Moro when the headdrop method is applied in infants suffering from Down's syndrome. Here it was not the intensity of the stimulus but the possibility of applying the stimulus which determined the result.

It is noteworthy that flexion of hands and fingers ("fisting") inhibits the Moro reaction considerably. This is not so obvious in newborn infants in whom the elicitation of the reflex seems to overbear the inhibiting influence of fisting. In older infants, especially at the age of 2 - 4 months, when spontaneous fisting often occurs (together with a propensity to flexion posture of the arms and body during lifting), this inhibiting influence is much more evident and has to be recognized in order to be able to elicit a proper Moro reaction.
Prechtl's (1965) demonstration that a slight pull on the wrists inhibits the abduction/extension of the Moro reaction effectively in favour of the adduction/flexion components (teleologically important in the case of a young monkey clinging to his mother while she climbs trees) should not be confused with this general inhibition of the two components of the Moro.
Lamote de Grignon (1955) mentioned this inhibiting effect but did not counteract it before eliciting the Moro response. His finding that hand- and finger-movements as a part of the Moro reaction disappear earlier than arm- and shoulder-movements, can be attributed rather to his method of standardization than that it would be characteristic of the developmental course of the Moro reaction. If one ensures that the infant's hands are open during the elicitation of the Moro, hand- and finger-movements may be observed as the last manifestation of the presence of the response.

During the development of the Moro reaction elicited by the hit-method a fast and abrupt adduction/flexion movement appeared as has been mentioned in the description of the Moro responses. This happened from about the sixth month onwards, though not in all the infants; neither did it appear consistently in individual infants. Sometimes the fast and abrupt movements appeared after a complete dissolution of the slow and smooth movements scored as 1 of 2. This movement type did not merely consist of flexion and adduction of the arms but involved the whole body. As stated before, it showed resemblance to the fright reaction of older children and adults, consisting of a mass flexor-pattern in which the whole body partakes. Phenotypically this movement pattern is quite distinct from the adduction/flexion component of the Moro reaction; this view is supported by the lack of any relationship between its occurrence and any of the components of the Moro reaction as elicited by the various methods.

The argument that it occurred only as a result of a hit on the surface was refuted by the report of several mothers; they stated that their infants, who showed this reaction, displayed similar movement patterns on sudden fright. When McGraw (1943) asserts that the abrupt and fast movement pattern is the "mature" phase of the Moro, she confuses the actual Moro, which is a vestibular reaction, with fright reactions which are of quite a different character. It is not impossible that an acute fright-reaction provokes a Moro reaction. This may be the case in very young infants. The Moro reaction may then outstrip the original fright movement to such an extent that the latter is no longer recognized as a separate phenomenon. One may contend that the fast adduction/ flexion movements seen after the age of six months represent a mature fright reaction (i.e. a response to rather a-specific stimuli). The inconsistency of their occurrence, inter- as well as intra-individually, may be accounted for by the infant's adaptation to various kinds of noises in his environment, and by differences in intensity of the stimuli or differences in the state in which the infant happens to be during the stimulation.

The term "fright reaction" or "fright movement" should not be confused with the term "startle" which has gradually become the term with which mass-movement patterns occurring during sleep are described. Although possibly in the very young infant similar mass-movement patterns may be caused by sudden stimuli, which subsequently elicit a Moro reaction, they may still not be considered as identical with the fast and abrupt fright movement occurring at older ages. The latter is a well organized flexor motor pattern, while the startle of the newborn and very young infant is more irregular, not so well organized and often considerably slower.



# Chapter X Group IV: Items with so many inconsistent changes during the follow-up period that a definite developmental sequence could not be established

In this chapter those items will be discussed which show evident changes during development, but for which the operationalization of the moment of the final change turned out to be very difficult. This might be due to the fact that no stable phase was reached before the end of the follow-up study or to the fact that the response, which was reflex in origin, gradually merged into voluntary motility.

The items are listed in Table VIII. They are ordered in subgroups for reasons of convenient presentation. When the definition given for inconsistencies is applied (see chapter II) the items of this group are characterized by a high frequency of relapses in score in a large number of the infants. However, as the developmental sequence of these items could not always be operationalized adequately, it is doubtful whether the relapses may be called inconsistencies, as defined and applied in the previous chapters. (Table VIII, page 114)
As also the moment of the final change and consequently the length of the developmental range usually could not be defined unequivocally the items of this group were omitted from the analysis of the interrelationships.

## Observation of posture and motility

### Spontaneous posture of the hands

*Procedure:* The infant was put in supine position. During the initial observation period the predominant spontaneous posture of the hands was recorded.
State 3 or 4. Possible scores were: hands closed or fisted, open hands and arbitrary or voluntary postures without a predominant pattern.
Due to the amount of spontaneous motility and the rapid development of functional motility of the hands it was difficult to operationalize a reliable final change. In the newborn period the majority of the infants showed flexion of the fingers although their hands were not tightly fisted. At the second assessment, however, i.e. at the age of about 5 weeks, two thirds of the infants displayed tightly closed hands during the greater part of the observation period. During the third assessment, this flexion posture was still predominant in about half of the infants, but subsequently decreased rapidly. The disappearance of this flexion posture of the hands preceded the first decrease of intensity of the palmar grasp reflex, occurring at about eight or nine weeks. It was followed by a phase during which the hands were mainly open, or showed alternating opening and closing movements. These movements could hardly be distinguished from arbitrary movements, although the two phases seemed not to be identical. As spontaneous grasping behaviour and goal-

directed motility of arms and hands developed rapidly during the same period, it seems probable that the phases of open hands and/or alternating opening and closing movements merge so rapidly into the phase of voluntary and goal-directed hand-motility that they cannot be differentiated, the frequency of the follow-up assessments of the present study taken into regard. As for the development of the posture of hands, it is noteworthy that between 4 and 10 weeks of age closed hands may be observed in many normal infants. The influence of fisting on the Moro reactions has been discussed in the paragraph dealing with the development of the latter.

**Posture of head and trunk during prone suspension (Landau)**

This item is dealt with under the heading "observation of posture and motility" because it consists of a motor phenomenon elicited by keeping the infant in a specific posture without applying a specific stimulus as is done in the case of the items described in the section ,,reflexes and responses".

*Procedure:* The examiner kept the infant in prone suspension, supporting him under the thorax with one hand (see Prechtl and Beintema, 1964).

State 3 and 4. The posture of head and trunk was described.

*Recording:*

0. The infant was not able to straighten his back; his body and head hung down limply; an evident downward concavity of the spine could be observed.
1. The infant straightened his back, but he was not able to lift his head sufficiently high so that his occiput would be in one line with his spine.
2. The infant straightened his back so that he kept head, shoulders and pelvis in one horizontal plane.
3. The infant lifted head and pelvis so that he showed an upward incurvation of his spine.
4. The infant lifted his head and pelvis and hyperextended his spine so intensively that an evident upwards concavity of the spine could be observed (Landau).

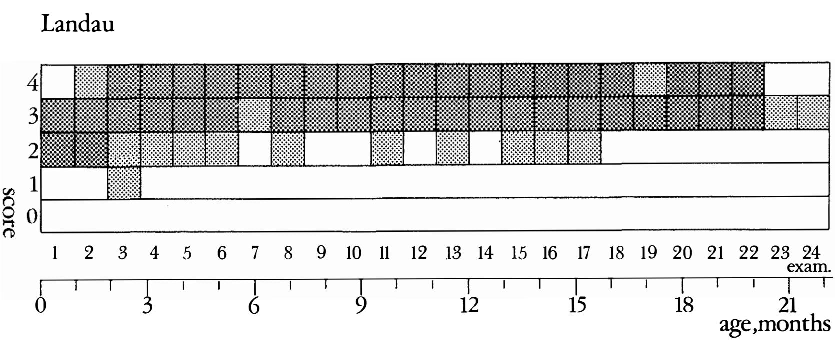



Fig. 43

The prediction band for the scores for posture of head and trunk during prone suspension is presented in figure 43. As a score 0 represents a hypotonia of neck and trunk musculature and normotonia was one of the selection criteria for the present group, none of the infants of the sample obtained a score 0 at the newborn examination. Neither was this the case during the course of development. Two infants obtained a score 1 at the third assessment. During the first and second assessments half of the infants obtained a score 2, but subsequently the majority of infants obtained a score 2 or 3. Between the fifth and tenth assessment, i.e. between about 20 and 40 weeks of age, more than 70% of the infants displayed a strong incurvation of the back, thus obtaining a score 4. After the 40th week a score 2 occurred with increasing frequency. Yet at the age of one year half of the infants still showed a strong incurvation of the spine and about one third of the infants who were still present in the study group, showed this posture until the end of the follow-up period.

The Landau can be reinforced by imposing passive hyperextension of the neck. If this was done between 24 and 40 weeks of age an evident extension of spine, hips and knees was observed in more than 90% of the infants.

After the age of one year this movement-pattern could still be elicited in more than half of the infants, but it became increasingly difficult to distinguish an actual Landau from voluntary motor behaviour consisting of the infant's active resistance against imposed manipulation. Landau, quoted by Mitchell (1960), found the strong upward incurvation of the spine between the age of seven weeks and fifteen months, André-Thomas located it on the time-scale between the ages of three and seven months (André-Thomas and St. Anne-Dargassies, 1952), while Mitchell mentions three months to about one year as the period during which a strong incurvation occurs. Peiper (1963) considers the vestibular system as the preponderant afferential input. André-Thomas states that neck-propriocepsis plays the main role, while Mitchell assumes that this posture is a combined effect of labyrinthine, neck and visual reactions.

Indeed the Landau consists of two types of reflexes, the first one originating in the labyrinths, resulting in an orientation of the head in space (head lift) which in its turn, due to the imposed posture of the neck, results in a „kettenreflex", namely an extension of spine, hips and knees.

The finding that gradually the response is found more frequently from the age of two months onwards suggests that visual input may play a guiding and reinforcing role in the orientation of the head, although at the same time the power of the neck muscles increases so that the head can be lifted more adequately and the well-oriented head posture can be maintained more easily (see also Bobath (1966)).

The findings demonstrated a large variability of postures inter- as well as intra-individually, which is reflected by the large number of inconsistencies. Forty-four of the infants showed ninety-three inconsistencies.

The number of inconsistencies per infant ranged from one to five, but there was no difference between boys and girls. The large variability suggests that active voluntary motility, and the behavioural state, play an important role in the maintenance of the posture in prone suspension, especially after the first months. It is remarkable that only seven of the total number of 93 inconsistencies occurred before the age of 16 weeks. At this age more than 80% of the infants showed a mild upward incurvation of the spine and an evident head lift with elbow support and exploratory looking around in prone position. The variability of the posture in prone suspension increased with age, as is evident from the shape of the prediction-band. The development of posture in prone suspension may therefore be considered as an illustration of the way in which reflex-mechanisms are incorporated in spontaneous voluntary activity.

## Reactions and responses

### Reaction to tactile stimulation of the dorsum of hand and fingers

*Procedure:* With a finger the examiner gently stroked the dorsum of the infant's hand and fingers distalwards, starting from the back of the hand and ending at the nails of the fingers. State 3 or 4.
The response consisted of a flexion of wrist and fingers followed by an extension which then resulted in grasping the stimulating finger.

*Recording:*

0. No response, or only an opening of the hand without subsequent grasping.
1. Weak response, consisting of a slow flexion and extension movement followed by inadequate grasping, which seemed to occur accidentally.
   An opening of the hand followed by grasping occurring when the stimulus had reached the distal half of the fingers, was also scored 1.
2. Evident and rapid response immediately after stroking the back of the hand.

At the newborn examination all the infants opened their hands on tactile stimulation of the back of the hand, but grasping of the stimulating finger did not occur. This mere opening of the hand, which may be regarded as the opposite of the palmar grasp reflex (i.e. closing the hand on stimulation of the palm) was not considered as a positive reaction to dorsal stimulation as operationalized here and therefore was scored 0. At the second examination 16% of the infants showed a slow flexion of hand and wrists followed by an extension, but without adequate grasping. A complete response was obtained from the third assessment onwards, with a rapidly increasing frequency, reaching its peak at the fifth examination (67%). At the same time, spontaneous grasping developed rapidly, and the area of the back of the hand from which the response could be obtained, was displaced towards the distal end of the fingers.

Thus it became increasingly difficult to distinguish between active grasping and an involuntary response. Visual guidance of the grasping did not seem to be necessary, neither during the elicitation of the response in the first months nor afterwards, so that it was concluded that tactile stimulation was sufficient for the evocation of this manipulative motor pattern, even when it was incorporated in voluntary motility of the hands. A minority of the infants did not show the response during the whole period of the follow-up study.

The response shows a resemblance with the tactile placing reaction of the feet, and seems to play a role in the development of exploratory behaviour of the hands. Remarkably, its gradually merging into voluntary behaviour (which makes the distinction between the response and voluntary behaviour hardly feasible) occurs at about the same time when the intensity of the palmar grasp reflex diminishes. It may be argued that an interplay between the palmar grasp reflex and the reaction to dorsal stimulation of the hand and fingers plays a role in the development of voluntary grasping, in which they become incorporated subsequently.

**Palmomental response**

*Procedure:* With his thumbnail the examiner scratched the radial area of the infant's palm. The response consisted of a visible contraction of the mental muscles. State 3 or 4.

The responses were graded on a 3-point scale:

0. No contraction of the mental muscles.
1. Visible contraction of the mental muscles consecutive to the first stimulation only.
2. Evident contraction of the mental muscles as a reaction to at least three or four consecutive stimulations.

Visible contractions of the mental muscles were found in more than 80% of the infants during the first ten assessments. The ratio between the number of infants showing one and more visible contractions was 1 : 2 during the first assessments, and gradually changed into 2 : 1 during the ninth, tenth and eleventh assessment. The number of infants not showing any positive reaction increased from about 10% during the first ten assessments to more than half of the infants during subsequent assessments.

The palmomental reflex belongs to the group of the so-called brain stem reflexes. In clinical neurology they can be found in the case of brain stem syndromes, as evidence of an impairment of the brain. In healthy individuals often a weak visible response may be obtained but habituation takes place rapidly. If one considers the palmomental reflex as an expression of brain stem-mechanisms, its developmental changes during infancy reflect the incorporation of brain stem-mechanisms in the organization of the brain during development.

## TABLE VIII

**Items with many inconsistencies and a protracted developmental course, so that a definite developmental sequence could not be established**

*Observation of posture and motility*

Spontaneous posture of the hands
Posture of head and trunk during prone suspension (Landau)

*Reactions and responses*

Reaction to tactile stimulation of the dorsum of hand and fingers
Palmo-mental response
Knee jerk
Ankle clonus
Plantar grasp
Magnet response
Crossed extension response
Positive supporting reaction
Tactile placing of the feet
Schaltenbrandt reaction
Bauer reaction
Galant response
Threaten reflex

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### Knee jerk

*Procedure:* The examiner kept the leg in semiflexion of hip and knee joint and gave a brisk tap on the patella-tendon a little below the patella. State 3. The response consisted of a contraction of the extensor muscles of the knee.

*Recording:*

0. No visible or palpable reaction.
1. Weak contraction of the knee extensors.
2. Evident contraction of the knee extensors.
3. Strong response, often with after-beat, consisting of an expansion of the reflexogenic zône below the insertion of the patella-tendon at the tibia, and/or evident co-contractions of the adductors of the opposite leg.

An absence of the response or a weak contraction was not observed during the whole follow-up period in any of the infants. During the newborn examination 86% of the infants showed a medium response, while in 14% of the infants a strong response was observed. At the second assessment the reverse took place and until the tenth examination, i.e. until the age of about 40 weeks, in more than 80% of the infants a strong response was found. Subsequently the percentage of strong responses decreased. There was no relation with the moment of standing or walking. Because the infants who had become able to walk unsupported were omitted from the follow-up study, it could not be determined at which age a strong knee jerk had disappeared.
A clonic knee jerk was observed in one infant at the eighth assessment, without the infant being evidently in a poor condition.

According to André-Thomas below the age of six to seven months the knee jerk is often found to be accompanied by a contraction of the contralateral adductor-muscles while the reflexogenic zone is extensive (André-Thomas and St. Anne-Dargassies, 1952). Paine (1960) has the same opinion. In the present study this type of knee jerk is comparable with a strong response (score 3).
A strong response was observed in a varying number of infants, not only during the first half year of life but also afterwards. Yet the highest frequency of exaggerated responses was found during the first half year of life, which is in accordance with the finding of the authors cited above.

**Ankle clonus**

*Procedure:* The infant was put in supine position; the leg was fixated with the hip and knee in semiflexion, and the foot was abruptly dorsiflexed, which caused a sudden stretch of the calf muscles. Clonic beats of the foot were counted if present. State 3 or 4.

*Recording:*
0. No ankle clonus present.
1. One to three beats.
2. Four to six beats.
3. More than six beats.

During the newborn examination in about half of the infants an ankle clonus was found; 16% of the infants showed four to six beats and in 4% of the infants more than six beats of ankle clonus were found. During the second assessment 30% of the infants showed one to three beats of ankle clonus, while in 20% of the cases four to six beats were found. Subsequently the frequency of ankle clonus decreased rapidly, but until the end of the follow-up study ankle clonus of one to three beats could irregularly and inconsistently be found in some infants of varying identity.

**Plantar grasp**

*Procedure:* The plantar grasp was elicited according to Prechtl and Beintema (1964), by pressing the thumb against the sole just below the toes. State 3 or 4.
The response consisted of a flexion of the toes.

*Recording:*
0. No reaction.
1. Slight flexion of the toes.
2. Evident and sustained flexion of the toes.
3. Strong and sustained flexion of the toes.

During the first nine assessments, i.e. until the age of about 36 weeks, more than 80% of the infants obtained a score 2. From the seventh assessment onwards, the intensity of the plantar grasp decreased in an increasing but varying number of infants.

From the 14th assessment onwards, in some infants a negative response was scored, but at the same time the sample size decreased as a result of infants becoming able to walk unsupported. Still there was no clear relationship between a disappearance of the plantar grasp and the onset of walking unsupported. An exaggerated response occurred in a small and variable number of infants (not exceeding eleven), at some time during the first year of age. In one infant an exaggerated response was found at the 19th assessment, i.e. at the age of about 75 weeks. The development of the plantar grasp appeared to be quite variable, which is illustrated by the occurrence of many inconsistencies in the responses, i.e. 63 in 36 of the infants. The inconsistencies were distributed randomly over the length of the developmental course and it was impossible to define a stable final change within the period of the follow-up study. Koupernik and Dailly's (1968) view that the plantar grasp is less intensive than the palmar grasp reflex could not be confirmed. Paine's conception that the plantar grasp would decrease in intensity at about eight months, which suggests that it would disappear shortly afterwards, is not supported either by the present findings (Paine, et al. 1964). The results are in accordance with Zappella's finding that the plantar grasp can be observed during the whole first year of life (Zapella, 1966). As in the present study only one type of stimulation, i.e. pressure with the thumb, was applied, the effect of the quality of the stimulus on the response could not be investigated (Zapella, 1967). Poecks' opinion that the plantar grasp disappears when the infant starts to stand up and walk, could not be confirmed (Poeck, 1968).

**Magnet response**

*Procedure:* The magnet response was elicited by gently touching the soles of the infant's feet while he was lying in supine with flexed hips and knees, and by slowly withdrawing the stimulus without losing contact with the sole of the foot.
The response consists of a gradual extension of the legs, so that the foot does not lose contact with the stimulus (Prechtl and Beintema, '64). During the first three assessments a positive response was obtained in more than 80% of the infants. It became increasingly difficult to distinguish between a positive magnet response on the one hand and voluntary flexion/extension movements of the legs on the other hand, due to the increasing motility of the legs with increasing age.

**Crossed extension response**

*Procedure:* The infant was put in supine position. With one hand the examiner fixated the infant's leg in extension; with his other hand he applied a slightly painful stimulus to the sole of his foot, using his thumb nail. The response consisted of a flexion of the opposite leg followed by an extension and adduction.

During the first four assessments, i.e. until the age of about 16 weeks, a response consisting of a stereotyped flexion followed by an extension and adduction of the opposite leg was obtained. From about the third assessment onwards, however, the infants were remarkably capable of directing the extension movement of the opposite leg towards the stimulus.This seemed to be an active protection reaction. Moreover, from about the fourth assessment onwards the flexion pattern of the opposite leg became increasingly variable, while at the same time the infant showed an increased generalized motility consecutive to the stimulation. It was concluded that the reflex-like reaction of the first months rapidly merged into an active defense pattern, which could not be called a crossed extension reflex. This is in accordance with Saint Anne-Dargassies' view that the neonatal response rapidly develops into an active motor pattern which then remains present throughout life (Saint Anne-Dargassies, 1964).
Paine points out that the response pattern observed in normal infants should be distinguished from the crossed extension reflex seen in infants with spinal cord lesions. In this latter reflex the neatly directed extension towards the stimulus is not found; it is also more stereotyped (Paine, '60).

**Positive supporting reaction**

*Procedure:* The examiner supported the infant under the shoulders and placed him on a flat surface in standing position. He took care that this surface had an agreeable texture and temperature. The response was considered to be positive if the infant extended his legs in order to bear weight. State 3 or 4.

*Recording:*

0. No extension of the legs, the infant could not bear weight, his legs gave way immediately.
1. Evident extension of the legs, of short duration. The infant could bear weight only momentarily.
2. Evident extension of the legs, the infant was able to bear weight for at least 5 seconds.

It appeared to be hardly feasible to distinguish between a positive supporting reaction and active standing, as the one gradually merged into the other. Thus it was impossible to determine a distinct moment of the final change of the positive supporting reaction.
No reaction was found in about two thirds of the infants during the first five assessments; subsequently the number of negative responses decreased and from about the eleventh assessment onwards, i.e. from the age of about 44 weeks, more than 90% of the infants could bear weight if placed on their feet. An evidently positive response, with weight bearing for longer than five seconds, was found during the first half year of life in 15% of the infants or less. Thus a positive reaction seemed to coincide with the phase in which an infant could stand with support but was not yet able to stand up and sit down again of his own

accord. Still, there was no relation between the occurrence of a strong positive supporting reaction and the age of standing with support. The positive supporting reaction defined in this way appeared to be very inconsistent, 71 inconsistencies being spread between 40 infants .There was no difference between boys and girls.

McGraw (1943) and André-Thomas (1952) made a distinction between two phases of the positive supporting reaction. The first one would be present during the first months of life and would be followed by a phase of decreased intensity or even disappearance of the response. subsequently the second phase would set in, belonging to active standing up behaviour. Such a biphasic developmental course was not found in the present study. The inconsistencies were scattered over the whole period of the developmental course. No relationship could be found with the ocurrence of the magnet response, which is sometimes regarded as a positive supporting reaction in a horizontal position (Peiper, 1963).

Peiper contended that for a positive supporting reaction weight bearing was not indispensable. In the case of the magnet reaction only tactile stimulation is applied, in the case of the positive supporting reaction tactile stimulation is followed by proprioceptive stimulation, as a result of the weight on the feet. If one excludes possible vestibular influences on the response, it may be assumed that in the positive supproting reaction tactile and proprioceptive stimulation are both involved and that the latter stimulation reinforces the effect of the former. Yet it is possible that vestibular input does play an important role in the generation of the response. In that case the positive supporting reaction may be another example of the phenomenon, proper to normal development, that a phenotypically comparable motor behaviour may result from various mechanisms which finally converge into voluntary motor behaviour. Actually, this illustrates the main difference between a normal and a pathological nervous system, in which this variable interplay between various brain mechanisms does not occur, resulting in a decrease of variability.

**Tactile placing of the feet**

*Procedure:* The examiner supported the infant under his shoulders and kept him in vertical suspension. He brought the dorsum of the feet into light contact with the edge of a table. The response consisted of an initial plantar flexion of the foot, followed by a flexion of the whole leg which in its turn was followed by an extension of the legs so that finally the foot was placed on the table. This placing may or may not be accompanied by weight bearing. State 3 or 4.

During the first two assessments more than 80% of the infants showed a brisk placing response without weight bearing. This percentage decreased during the subsequent assessments, so that during the fifth and sixth assessments about half of the infants showed a brisk response. Subsequently the percentage of brisk responses increased and from the eleventh assessment onwards more than 80% of the infants again show-

ed a brisk placing response, which at that time was accompanied by weight bearing. In only one infant was the response completely absent during the fourth, fifth and sixth assessment. This developmental course suggestst the involvement of various brain mechanisms in the generation of this motor behaviour. During the first months the stimulation is mainly tactile, while proprioceptive reinforcement does not enlarge the effect. During the second half of the first year of age proprioceptive influences seem to play an increasingly important role. This phase coincides with the initial phase of standing-up behaviour. Evidently the mechanisms for the initial placing reaction are incorparated in the organization of voluntary standing behaviour. This is in accordance with Zapella's finding that various factors, as e.g. the temperature of the stimulus, influence tactile placing of the feet in the first months of life, but that this is no longer true in subsequent months. In his view the initial placing reaction can mainly be attributed to mid-brain activity, while the various characteristics of the later placing reaction indicate a cerebral cortical mediation of the response as a part of voluntary placing. (Zapella, 1967).
The majority of the infants showed one or more inconsistencies, scattered over the whole developmental range, but there was no difference between boys and girls. The large number of inconsistencies (74) may be regarded as an illustration of the variability of performance characteristic of the normally developing nervous system, in contrast with the stereotyped performance typical of the damaged nervous system.

**Schaltenbrandt reaction**

*Procedure:* The Schaltenbrandt reaction is the reverse of the Landau; it is often called the Landau 2. While keeping the infant in prone suspension the examiner flexed the infant's head. The positive response consisted of a flexion of trunk and hips.

The results were comparable with the results of the Landau. Thus the Landau and Schaltenbrandt reactions need not be regarded as essentially different. The occurrence of inconsistencies was also similar in both cases, although in the case of the Schaltenbrandt reaction the inconsistencies appeared to be scattered over the whole developmental course; they were not limited to the latter part as was the case with the Landau. This may reflect the infant's increased active resistance against flexion of his head in prone suspension, which could already be observed at a young age.

**Bauer reaction**

*Procedure:* The infant was put in prone position with hips and knees flexed. The examiner placed his hands behind the infant's feet so that he touched the soles. A positive response consisted of a forceful extension of hips and knees, resulting in forward progression of the infant. State 3 and 4.
During the newborn examination all the infants showed an evident forceful extension of hips and knees; during the second examination this

was the case in only 31% of the infants and afterwards the percentage decreased rapidly. During the second assessment a weak reaction was found in 53% of the infants, but this percentage also decreased rapidly during the subsequent assessments. Still, during the whole period of the follow-up study a smal minority of infants of varying identity (one or two at a time) inconsistently showed an evident or weak response to this type of stimulation of the sole of the foot in prone position. These responses seemed to be related preponderantly to the amount of motor activity of the infants; it was very difficult, and in some instances even impossible, to distinguish between the Bauer reaction on the one hand and active motility on the other hand. There appeared to be no relationship with the development of locomotion in prone.

**Galant response (incurvation of the trunk)**
*Procedure:* The infant was put in prone position. With a pin the examiner scratched the skin of the infant's back slowly and gently from the shoulders downwards, at about three cm laterally from the spine. The response consisted of an incurvation of the trunk with the concavity on the stimulated side. State 3 or 4.

During the first ten assessments an evident incurvation of the trunk towards the stimulated side was found in more than 80% of the infants. This incurvation was characterized by a stereotyped contraction of the back muscles, resulting in a consistent and reproducible movement pattern. This protracted persistance of the Galant response is in contradiction with André-Thomas' view that the response should only be present during the first weeks of life (André-Thomas and Saint Anne Dargassies '52). Koupernik and Dailly ('68) state that the response disappears gradually in the second half year of life. In the present study from the age of about 40 weeks onwards the trunk movements became increasingly heterogeneous; as a consequence it became increasingly difficult to distinguish between an evident incurvation of the trunk and a "tickle reaction". In the latter reaction the consistent and reproduceble movement pattern is lost. This reaction persisted in all the infants during the whole period of study. Thus a reliable Galant reaction which may have clinical significance in cases of spinal cord disorders seems to be present only during the first nine months of life.

**Threaten-reflex**
*Procedure:* The examiner moved his extended fingers rapidly towards the infant's eyes. He took care to avoid stimulation of the cornea. A positive response consisted of a blink of the eyes. State 3 or 4.

More than 80% of the infants did not show any positive reaction until the age of about 20 weeks. From that age onwards the number of positive responses increased rapidly. Still, 18% of the infants did not show a positive threaten reaction at the age of one year.

It is possible that environmental conditions affect the time of onset of this reaction. Factors like number, age and behaviour of siblings, the active playing behaviour of the father, and the presence of domestic animals seemed to be involved. The conclusion seemed justified that this reaction is partly age-dependent and partly environment-dependent. White found that a blink response to an approaching visible target developed rapidly between the middle of the second month of life and the age of four months (White, 1970). His findings are not comparable with the findings of the present study as his design was more elaborate and adapted to a specific research of the development of this particular reaction. He stated a close correspondance between the development of the response and the flexibility of what he calls the "accommodative system". Also, the findings of the present study point at a comparable developmental course of these two phenomena.

**Comment**

The items of this group can be divided into two subgroups. The first group contains those items of which the developmental course had not yet finished at the age of walking free. The second contains those items which showed no evident final change, due to a gradual merging into voluntary activity. Consequently it was not possible to estimate the developmental range, i.e. the developmental rate, and the frequency of inconsistencies.

The first subgroup includes the knee jerk, ankle clonus, plantar grasp, Landau and Schaltenbrandt-reaction. The first three items are leg- and foot-responses, while the latter two involve the sensorimotor apparatus of neck, trunk and legs. Their protracted developmental course can be seen as an illustration of the cephalocaudad maturation of the nervous system. It is noteworthy that their, as yet unstabilized, development does not interfere with the development of standing and walking as defined in this study. Apparently, nervous mechanisms involving particular motor activities can be operational while some components have not yet reached stabilization. It stands to reason that walking free, as defined in this study, is not a final point in the development of this motor behaviour, nor does it reflect a final phase of maturation of the brain mechanisms involved.

The final maturation of these mechanisms is not only reflected by the differentiation of walking in for instance toddlers, but also by the final changes in the items of this subgroup.

The responses of the items in the second subgroup could be recognized originally as specific stimulus-responses, but gradually this specificity diminished so that finally comparable responses occurred during voluntary behaviour. It was not possible to distinguish an evident transition between elicited responses and voluntary motor patterns. Actually the main characteristic difference between those two was a voluntary use of the final motor pattern.

It seemed that during their development the infants gradually became able to make voluntary use of nervous mechanisms which originally operated more autonomously. A close inspection of the responses, however, made clear that there were distinct qualitative differences between voluntary and involuntary motor behaviour, but the final responses developed too gradually to be pinpointed to a specific moment. For instance, the reflex-like crossed extension following a nociceptive stimulus on the contra-lateral footsole of a very young infant differed essentially from the well-directed defense reaction of the older infant to the same stimulus. Still, it could not be ascertained at which moment the actual character of the response changed. The same can be said of items like the tactile placing of the feet, the positive supporting reaction or the Galant response. One may assume that the neural mechanisms involved become subordinated to newly developing mechanisms. The Galant response, for instance, cannot be observed after a particular age, because then a very complex tickle-response prevails.

The main difference between the items of this group and those of group III (chapter IX) lies in the fact that in the latter the final point of stabilization could be defined on the time scale more easily, because there was a conspicuous change in the expression of the neural mechanisms involved. In this connection issues of operationalization have to be taken into consideration; especially with regard to the items involving spontaneous motility of arms and legs it was difficult to decide whether to include them in group III or in group IV. This implies that no sharp distinction between group III and IV can be made. The majority of the items of group III deal with motor functions which are easily recognizable and which are frequently used in developmental testing-procedures. The changes in the maturing nervous mechanisms of these items seem to manifest themselves more conspicuously than is the case with spontaneous motility or many responses and reactions of group IV. Actually, the maturing brain mechanisms which are responsible for the great expansion of the infant's neurological repertory, can be divided into two categories. In the one category an integration of various, sometimes even originally independent, brain mechanisms takes place, as is the case in sitting without support or walking free, where mechanisms for motor movements and balance are involved. The other category contains those mechanisms which develop gradually. Items based on mechanisms belonging to the first category show developmental changes which can clearly be discerned.

Items based on mechanisms belonging to the second category may also show clearly discernable developmental changes, but they may show such a gradual development that transitions from the one developmental phase to the other become hardly discernable. Although there is a large overlap, the majority of the items of group III belong to the former, the items of group IV to the latter category.

From a clinical point of view the items of group IV can hardly be used in developmental testing or neurological diagnosis; only evident deviations such as consistent left-right differences seem to be useful for the latter purpose.

# Chapter XI Anthropometric and Psychosocial items

This chapter deals with the developmental course of several items which describe the group from an anthropometric point of view. These items are: body weight, body length, circumference of the skull and fontanels (Table IX).
They serve the purpose of documenting the present group. Also, some items will be discussed which may reflect psychosocial and autonomic development and which are usually included in the neurological examination. These items are: development of vocalization and speech, smiling, lacrimation and reaction to strangers (Table X).

| TABLE IX | TABLE X |
|---|---|
| **Anthropometric items** | **Psychosocial items** |
| body weight | Vocalization and speech |
| body length | smiling |
| skull circumference | reaction to strangers |
| fontanelles | lacrimation |

## Anthropometric items

### Body weight

At birth the weight-range of the infants was between 2800 and 4200 grams. Only one infant weighted less than 3000 grams and 8 infants weighted more than 4000 grams at birth.
During the assessments the infants were weighed with their clothes on, on the scales available in the respective households. During their development their weight ranged between the tenth and ninetieth centiles for the Dutch population, as presented by Van Wieringen (1972).

### Body length

Body length was defined as crown-foot length and measured while the child was in supine position. During the period of study the lengths of the infants ranged between the tenth and ninetieth centiles for the Dutch population, as presented by Van Wieringen (1972).

### Skull circumference

For the measurement of skull circumference the measuring tape was applied around the fronto-occipital diameter of the head. At birth about half of the infants had a skull circumference larger than 36 cm. When the present data are compared with the centile curves of Falkner (1958) (Dutch data are not available) there is a fair agreement.

### Fontanels

The variability of the size and closure of the fontanels was large. In three infants the anterior fontanel was closed at about half a year of age,

while in one infant the anterior fontanel was still palpably open at the age of 15 months. The size of the fontanels varied considerably among the infants. There was no difference between boys and girls. The findings are in accordance with Dileo's report that the statistical mean for closure of the anterior fontanel is at 13.5 months (Dileo, 1967) and with Popich's (1972) ranges of normal size.
The posterior fontanel was still palpable in 25% of the infants at the newborn assessment, but from the second assessment onwards no open posterior fontanel was found.

## Psychosocial items

### Vocalization and speech

In the present study speech was defined as vocalization aimed at communication. Spontaneous vocalizations e.g. crying, were not taken into consideration. During the examinations the mother was asked to communicate with the infant and the infant's reactions were scored on a 4-point scale. State 3 or 4.

*Recording:*

0. No vocalization at all.
1. Cooing, i.e. primitive vocalization, in which no specific vowels or consonants are discernable.
2. Vocalization consisting of vowels, usually a-sounds, with beginning articulation.
3. Vocalization consisting of recognizable words, irrespective of intentional use.

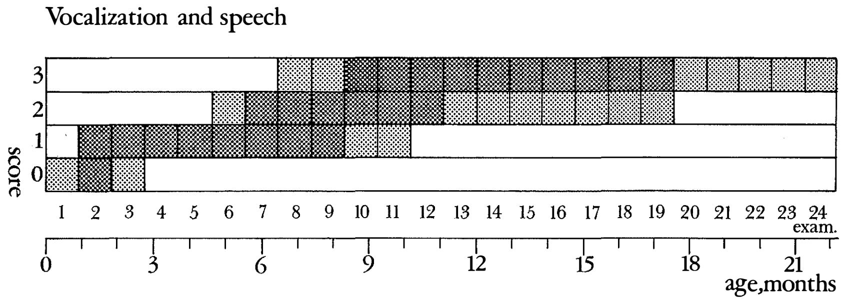



Fig. 44

The prediction band for the scores is presented in figure 44. Cooing appeared to be present in about half of the infants during the second assessment; it was the only type of vocalization found during the first 20 weeks. In some infants the use of vowels, particularly of the a-sound, started to occur at about the 24th week; subsequently the number of infants with a score 2 increased rapidly.

A small minority of the infants showed vocalization of a cooing quality as the only manifestation of speech development until the age of about 45 weeks. Four infants started to say words like "papa" and "mama" at the age of about 35 weeks, one quarter of the infants pronounced recognizable words at the age of about 40 weeks while at the age of one year more than 80% of the infants were able to say at least three or four recognizable words. This does not imply that the infants made proper use of these words.

In the boys the cooing type of vocalization was found somewhat earlier than in the girls; this difference was not statistically significant. There was a statistically significant difference between girls and boys with respect to the pronouncing of recognizable words ($p < 0.01$, Mann-Whitney U test). Hardly any inconsistencies in speech development occurred, neither in the group of the boys nor in the group of the girls.
It is evident that this mode of assessing speech development is completely insufficient if a scrutiny of the developmental course of vocalization and speech is aimed at. It only allows for a crude clinical appraisal of speech development, so that in case of doubt the infant can be referred to a specialized assessment. The findings are in accordance with reports in the literature (Byers Brown et al. 1974).

**Smiling**

Smiling was operationalized as communicative smiling at the mother. During the newborn assessment no communicative smiling was observed in any of the infants. During the second assessment one third of the infants smiled at their mother, while one fourth of the infants also smiled at other people. From the third assessment onwards, i.e. from the age of about 10 weeks, this was the case in all the infants. This is in accordance with the findings of Emde & Harmon (1972) with regard to exogenous smiling in infancy.
Ambrose (1961) found a later onset of smiling; he utilized a specific design (e.g. laboratory setting, unfamiliar face as a stimulus) and studied response-smiling in institutionalized infants. In his small group of infants he did not find differences of the onset of smiling between institutionalized infants and home-reared infants. His subtle design for the study of the development of reactive smiling during ontogeny, precludes a comparison with the findings of the present study, in which merely the absence or the presence of smiling were recorded.

**Reaction to strangers**

All the changes in posture, attitude and behaviour of the infant on approach of the examiner were defined as reaction to a stranger. It was scored on a 3-point scale:

0. No reaction.
1. Slight reaction, consisting mainly of a slight withdrawal, or a discontinuation of activities.
2. Evident reaction consisting of evident withdrawal for several minutes and/or crying.

As the examiner visited the homes of the infants only once per four weeks it was assumed that he remained more or less a stranger to the infants. However, this was not always the case; older infants in particular often seemed to recognize the examiner. As the infant's cooperation was a prerequisite for a proper examination, the examiner tried to avoid negative reactions as much as possible. This modulated his mode of approach and may explain the absence of intense withdrawal behaviour. In some infants slight reactions towards strangers, manifesting the infant's ability to distinguish between familiar und unfamiliar attendants, started to occur during the fourth assessment, i.e. at the age of about 16 weeks. One infant consistently showed an evident negative reaction towards the examiner from the third asessment onwards. Reaction towards the examiner, consisting of withdrawal behaviour and/or crying, occurred in one third of the infants at the seventh assessment, i.e. at the age of about six and a half months, three quarters of the infants showed such reactions at the age of about eight and a half months.

It is remarkable that consistent crying occurred only in a small minority of the infants. The majority of tht infants showed a withdrawal reaction of varying duration which could be overcome rather easily. The length of the adaptation period which was directly related to the intensity of the reaction to strangers, was the most protracted between the age of seven months and one year and after this age decreased rather rapidly.

**Lacrimation**

Lacrimation was defined as the presence of tears rolling down the cheeks during crying. In 61% of the infants lacrimation was observed at the second assessment, in 84% at the third assessment, and in all the infants during all the subsequent examinations.

# Chapter XII Sex differences

After the discussion of the single items of the neurological examination, which were subdivided into five groups, in this chapter the sex differences will be analyzed. This will be done only in the case of those items of which the four parameters could be defined, namely first change, final change, length of developmental range, and number of inconsistencies; consequently the items of group III and some of group II were included, beside speech development.

In the discussion of the single items sex differences were mentioned if present. In the present chapter it will be examined whether sex differences occur systematically.

In the literature it is assumed that during infancy differences in motor development between boys and girls are virtually absent. Neither André-Thomas, nor Gesell, McGraw or Paine, even consider the possibility of differences being present (Gesell and Amatruda, 1947; André-Thomas and St. Anne Dargassies, 1952; McGraw 1943; Paine, 1960).
The authors who do report sex differences often differ in opinion; Tanner (1970) for instance states that usually girls are ahead of boys in motor development, while Zachau-Christiansen (1972) concludes that the opposite is true; though he mentions the differences to be very small indeed.
Neligan did not find appreciable differences between boys and girls with regard to the milestones of sitting and walking free (Neligan and Prudham, 1969). On the contrary Hindley, in a re-analysis of Smith's data (1930) on different ethnological subgroups in the U.S.A., found that girls walked earlier than boys, although he could not confirm this finding in his analysis of five European longitudinal samples (Hindley et al. 1966; Hindley, 1967). Koupernik and Dailly (1968) refer to Stambak's statement that spontaneous unilateral motility of the arms (comparable to the asymmetrical spontaneous movement pattern in the present study) in girls would disappear somewhat earlier than in boys. Still it is generally agreed that girls mature somewhat faster than boys with regard to speech development (Illingworth, 1966; Neligan and Prudham, 1969).

In the present study differences between boys and girls were found in 17 items; they are listed in the tables XI and XII. Sex differences were estimated to be appreciable if they reached a statistical confidence level of 5 percent or lower (Mann-Whitney U test). The statistical tests were applied two-tailed, i.e. without any hypothesis about the direction of the differences, except in the case of speech with respect to which on the basis of the literature one might expect the girls to show a faster development than the boys. Sex differences were analysed for all four parameters, i.e. first change, final change, length of developmental range and number of inconsistencies.

## TABLE XI

**Items which showed significant sex differences in the favour of the boys (Mann-Whitney U test, two-tailed)**

| Item | first change boys earlier than girls | final change boys earlier than girls | range boys smaller than girls | inconsistencies boys less than girls |
|---|---|---|---|---|
| sitting up | .01 | | | |
| walking | | .01 | | |
| locomotion in prone position | .03 | | | |
| rolling over into prone position | | | | .02 |
| rolling back into supine position | | .01 | | |
| parachute reaction hands | | | .04 | .02 |
| foot sole reflex | | | .02 | |
| lip-tap reflex | | .03 | .01 | |
| fixation time | < .01 | | | |

## TABLE XII

**Items which showed significant sex differences in the favour of the girls (Mann-Whitney U test, two-tailed)**

| Items | first change girls earlier than boys | final change girls earlier than boys | range girls smaller than boys | inconsistencies girls less than boys |
|---|---|---|---|---|
| speech (one-tailed) | | .01 | < .01 | |
| convergence of the eyes | .01 | .01 | | |
| pupillary reaction on convergence | | < .01 | .04 | |
| conjugated eye movements | .03 | | | |
| type of grasping | | | | .01 |
| recoil | .04 | | | |
| spontaneous posture of the legs | | | .04 | |
| Moro lift, abduction/extension | | | | < .01 |

For the developmental assessment the final change can be considered as the most important parameter. Still from the developmental neurologist's point of view the first change, the length of the developmental range and the number of inconsistencies may be as important, as they may yield information about a differential developmental course of brain mechanisms in the case of boys and of girls.

The total number of 17 items with appreciable sex differences could be divided into two groups, one consisting of nine items with statistical differences in favour of the boys (Table XI), the other consisting of eight items with differences in favour of the girls (Table XII). Differences for all four parameters were found in none of the items; in the majority of cases a statistically significant difference was observed for one or two parameters only.
The differences in the parameters of one item always tended into the same direction.
The headings "boys earlier" and "girls earlier" suggest that there may be a systematic difference between the boys and the girls.
The common denominator of the subgroup "boys earlier" can be called "gross motor development". As for the subgroup "girls earlier", besides speech, items concerning the visual apparatus seem to predominate.
The difference in the number of inconsistencies during the development of type of grasping suggests that the fine motor abilities tend to develop more steadily in girls than in boys.

**TABLE XIII**

**Means and standard devations for both sexes of the items in which the boys were significantly advanced compared with the girls**

| | boys | | girls | |
|---|---|---|---|---|
| Items | M | sigma | M | sigma |
| sitting up, first change | 5.93 | 1.274 | 6.50 | 1.472 |
| walking, final change | 17.30 | 2.053 | 18.86 | 2.513 |
| locomotion in prone position, first change | 6.93 | 1.035 | 7.55 | 1.438 |
| rolling over into prone position, inconsistencies | 0 | 0 | 0.22 | 0.518 |
| rolling back into supine position, final change | 7.64 | 1.496 | 8.52 | 0.994 |
| parachute reaction hands, dev. range | 2.11 | 1.548 | 3.18 | 1.893 |
| parachute reaction hands, inconsistencies | 0.71 | 0.659 | 1.27 | 0.985 |
| foot sole response, dev. range | 4.11 | 2.897 | 6.00 | 3.367 |
| lip-tap response, final change | 4.43 | 2.218 | 5.39 | 1.50 |
| lip-tap response, dev. range | 1.93 | 2.089 | 3.13 | 1.632 |
| fixation time, first change | 2.11 | 0.315 | 2.43 | 0.507 |

## TABLE XIV

**Means and standard deviations for both sexes of the items in which the girls were significantly advanced compared with the boys**

| Items | boys M | boys sigma | girls M | girls sigma |
|---|---|---|---|---|
| vocalization and speech, final change | 12.68 | 1.827 | 11.68 | 1.836 |
| vocalization and speech, range | 10.21 | 1.750 | 9.09 | 1.900 |
| convergence of the eyes, first chagne | 3.11 | 0.629 | 2.65 | 0.573 |
| convergence of the eyes, final change | 4.54 | 1.261 | 3.57 | 0.945 |
| pupillary reaction to convergence, final change | 4.50 | 1.374 | 3.61 | 1.033 |
| pupillary reaction to convergence, dev. range | 1.11 | 1.197 | 0.57 | 1.161 |
| conjugation of eyemovements, first change | 1.32 | 0.548 | 1.09 | 0.417 |
| type of voluntary grasping, inconsistencies | 0.61 | 0.567 | 0.23 | 0.429 |
| recoil, first change | 2.18 | 0.390 | 1.96 | 0.367 |
| spontaneous posture of the legs, dev. range | 8.14 | 1.715 | 7.22 | 1.347 |
| Moro lift, abduction/extension, inconsistencies | 1.29 | 0.854 | 0.45 | 0.671 |

Inspection of sex differences in items which did not reach a 5 percent level of confidence reveals that items dealing with gross sensori-motor functioning often showed differences which pointed at a slightly higher developmental rate in the boys. This was the case with, for instance, head lift in supine, standing up, parachute reactions and footsole responses. Items dealing with spontaneous motility appeared to develop slightly faster in the girls than in the boys. Thus, an interpretation of the findings of the present study may be that there is a systematic developmental difference between the boys and the girls. While in gross motor areas the boys develop somewhat faster, the girls appear to be more forward in functional areas which require more subtle motor activities. This difference is very small and there is a large overlap of the findings with regard to the boys and the girls. In both areas some boys developed more slowly than some girls and vice versa. It is clear that clinically the differences do not have much practical value. This is illustrated by the Tables XIII and XIV, in which the means and standard deviations of those items are listed which show a statistically significant difference ($p < 0.05$); they clearly show the overlap between the boys and the girls. From this overlap the conclusion was drawn that the boys and the girls should be considered as belonging to one group when the description of the developmental course of the different items, as presented in the previous paragraphs, is involved.

One can only draw attention to the possible presence of systematic differences between boys and girls, for an adequate exploration of which a more specific design should be drawn up.

# Chapter XIII The parameters - intra-item relationships

The developmental course of the items has been described in terms of first change, final change, length of developmental range and number of inconsistencies. The first change and the final change define specific changes on the time-axis, i.e. in which the infant's age is involved, while the length of the developmental range reflects the developmental rate, independent of age. The number of inconsistencies quantifies one aspect of the variability of the responses during development, defined as relapses in score; they will be discussed separately (see chapter XIV).

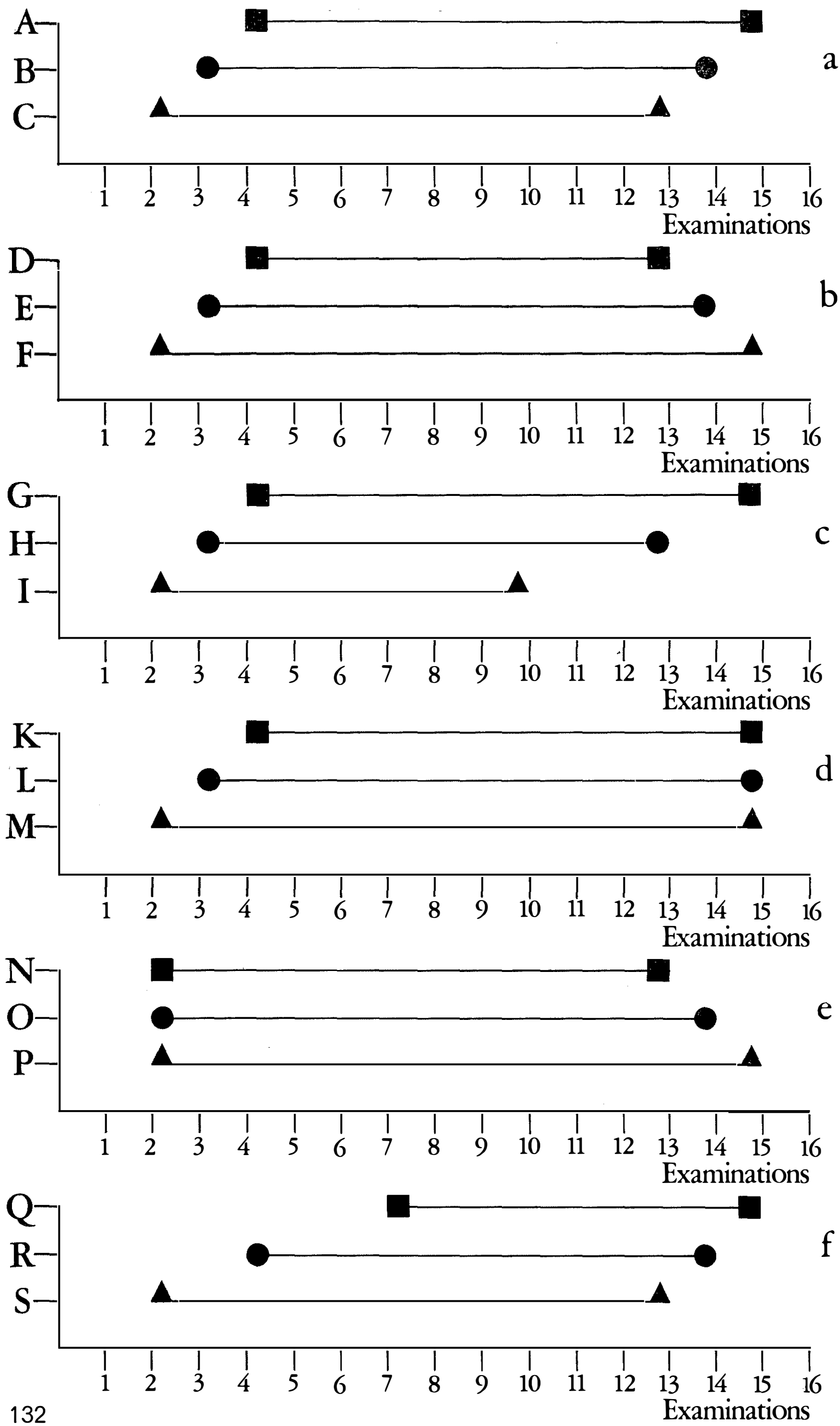
This chapter deals with the relationships of the parameters first change, final change, and developmental range occurring within single items; an analysis of the development in terms of age and rate may elucidate the maturation of brain mechanisms underlying these items.

What kind of relationships can be found between these parameters? There are six possibilities, which are presented schematically in fig. 45.

I. The first change and the final change can be related positively or negatively (fig. 45a and b.) In the case of a positive relationship the developmental range, i.e. the rate of the development, will be fixed, irrespective of the age at which the first and last developmental changes occur. It is self-evident that the moments of the first and last developmental changes (i.e. the first and final changes respectively) should have more or less equal variation ranges, tending to a similar direction. It is not surprising that this type of relationship occurs; it would imply a more or less fixed developmental rate of a neural mechanism.

   A negative relation between the first and final changes (fig. 45b) would imply a decrease of the developmental range (i.e. an increase of rate) if the first developmental change takes place late, and an increase of the developmental range in the case of an early first change. At the same time the variation ranges of the first and final changes would be of equal width, though tending to opposite directions. One can hardly imagine that such a relationship would be compatible with a normal and harmonious development.

II. The next pair of possible relationships are a positive and a negative relation between the first change and the developmental range. They are presented schematically in fig. 45c and d. In the case of a positive relationship, an early first change (i.e. a low value on the time scale) would imply a short developmental range, and a late first change would imply a protracted range, i.e. a slow developmental rate. This latter possibility can be expected in the case of neurologically damaged infants who start to develop late and with increasing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Examinations

age lag behind more and more. Maybe the former situation (i.e. an early first change related to a fast developmental rate) can be observed in slightly impaired infants, for instance in infants suffering from the hyperexcitability syndrome. Some of these infants may start to develop for instance locomotion at an early age and may be able to walk several months before the age of one year (personal observation). It seems unlikely that during a normal development there would be a positive relationship between the first change and the developmental range.

A negative relation between the first change and the developmental range (fig. 45d) reflects a late start and a "catching-up" during development so that the last developmental change still takes place "on time". This may imply that the moment of the last developmental change is fixed, while the moment of the first developmental change may vary.

Fig. 45d shows that the variation range of the final change must be zero, or at least considerably smaller than the variation range of the first change. Although a zero variation range of the final change is hardly compatible with normal development, still, theoretically speaking, the variation range of the final change may be smaller than the variation range of the first change. The report of some mothers who state that their various infants all walked at about the same age may serve as an example of a relatively small variation range. Presumably there are families of "early walkers" and of "late walkers". On a larger scale, systematic racial differences in motor development may illustrate relatively narrow variation ranges of developmental changes. Also, in patients who have suffered from a disease which interfered with their development, a "catching-up" is often observed; thus this type of relationship can be expected both in a normal and in a slightly deviant development.

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Fig. 45:

Diagrams representing the theoretical relationships between the first changes, the final changes and the developmental ranges.
Vertical axes: codes for imaginary cases.
Horizontal axes: number of examinations.
The dots, squares and triangles represent the first changes and the final changes respectively of the imaginary caes, lettered A till S.
The distances between the dots, squares and triangles reflect the lengths of the developmental ranges.

a: positive relationship between the first and final changes.
b: negative relationship between the first and final changes.
c: positive relationship between the first change and the developmental range.
d: negative relationship between the first change and the developmental range.
e: positive relationship between the developmental range and the final change.
f: negative relationship between the developmental range and the final change.

III. The third possibility implies a positive or a negative relationship between the developmental range and the final change (fig. 45e and f). In the case of a positive relationship, the moment of the last developmental change is determined by, or determines the length of, the developmental range. Fig. 45e shows that for this relation the variation-range of the first change must be zero or very small, at least much smaller than the variation range of the final change. This relationship is also an example of a fixed moment of a final developmental change. In this case the variation range of the final change may be considerably wide, while in the other type of programming of the final change the variation range of the first change appeared to be variable (cf. fig. 45d). In the former instance, the moment at which the first developmental change occurs, does not have any predictive value, as this moment is rather constant, while the final change is variable; in the latter (i.e. the negative relation between the first change and the developmental range) this may be the case, though actually this is based on knowledge that the moment of the last change is rather constant. This relationship seems to be compatible both with normal and with deviant development.

There might be a negative relation between the developmental range and the final change (fig. 45f) if a late occurrence of the last developmental change were accompanied by a short developmental range, i.e. if the first change took place extraordinarily late, so that after all the developmental range turned out to be quite short. This might be considered as a kind of "catching up" during development; the infant may start very late and end relatively early, though compared with the average infant he is still rather late because there was not enough time to catch up completely.

It is improbable that such a situation would occur during normal development. The opposite, i.e. an early final change with a very long developmental range, which means that the first change must have taken place at an excessively early moment, seems to be incompatible with any kind of development.

It can be concluded that in a group of healthy infants intra-item relationships between the first and the final changes (positive) are likely to occur, reflecting a preprogramming of developmental rate, also between the first change and the developmental range (negative), and between the final change and the developmental range (positive); the latter two reflect a preprogramming of the moment of the last developmental change independent of the developmental rate. Between these schematic possibilities transitions may be observed, dependent on the width and the symmetry of the variation ranges of the first and final changes.

Fig. 45 shows that a positive relationship between the developmental range and the final change or between the first and final changes (cf. fig. 45a and e) need not be incongruous, provided that the variation-ranges of the first change increase in the same direction as those of the final change. In the case of similar variation-ranges of the first and final

changes, a positive relationship between these two will be found. If the variation-ranges of the first change are smaller than those of the final change it is likely that a positive relationship between the developmental range and the final change is found.
However, it is highly improbable that a positive relationship between the first change and the final change is accompanied by a negative relationship between the first change and the developmental range (cf. fig. 45a and d) in one single group of infants.

In table XV the correlation-coefficients ($p < 0.01$) of the Pearson Product Moment correlations of the intra-item relationships are summarized (Appendix C presents the means and standard deviations as a measure of the variation-width). It appears that only those relationships which were expected are found. Relationships which were supposed to be incompatible with normal development are absent. However, for seven items a combination of relationships was found which was said to be unlikely to occur in a homogeneous group of infants. These seven items show intra-item relationships between the first change and the developmental range (with negative correlation-coefficients as expected) with or without positive relationships between the developmental range and the final change (both reflecting a preprogramming of the final change) but they also show a (positive) relationship between the first change and the final change.
Six of these seven items deal with a nervous function concerning sitting. This is evidently the case in the items "sitting up", "posture during sitting", "duration of sitting" and "visual following of an object with rotation of head and trunk during sitting". In adequate acoustical orienting comparable brain mechanisms may be involved, which enable the infant to rotate his head and body towards the stimulus, while in many infants the final change of rolling over from prone into supine position consisted of sitting up instead of merely turning into prone position. On the basis of the ideas about the possible combinations of relationships mentioned above, one may assume that with regard to the development of these items, two subgroups of infants should be distinguished. Indeed two distinct subgroups of infants were found to exist, as is illustrated by the plotting of the moments of the first and the final change and the developmental range of the item "duration of sitting" (fig. 21 and 22).
The other combinations of relationships, presented in Table XV are in agreement with the theoretical considerations mentioned above. For the majority of items the final change appears to be more or less fixed, though with different variation widths (see Appendix J) as is reflected by the occurrence of relationships between the developmental range and the final change often combined with (negative) relationships between first change and developmental range. It is remarkable that the latter relationships mainly occur in items dealing with reflexes and responses (Table XV). Part of the items show a combination of relationships between the developmental range and the final change and between the first and the final change; from this one may conclude that both the de-

**TABLE XV**
**Correlation coefficients ($p \leqq 0.01$) of intra-item relationships of the items of group III, including speech development. The items are divided into a subgroup with and a subgroup without significant correlations between first change and developmental range, and are furthermore within the subgroups ordered to the height of the correlation coefficient of the relations between final change and developmental range (Pearson Product-Moment correlations).**

| Item | first change/ developmental range | final change/ developmental range | first change/ final change |
|---|---|---|---|
| Goal directed motility of the arms | | +971 | |
| Vocalization and speech | | +958 | |
| Spontaneous posture of the legs | | +946 | |
| Posture in prone position | | +937 | |
| Moro headdrp, abduction/extension | | +820 | |
| Locomotion in prone position | | +779 | +544 |
| Standing up | | +765 | +563 |
| Optical placing reaction of the hands | | +745 | |
| Rolling over from supine into prone position | | +743 | +401 |
| Parachute reaction of the hands | | +671 | +621 |
| Head lift in supine position | | +574 | +751 |
| Optical placing reaction of the feet | | +505 | +777 |
| Walking | | +493 | +794 |
| Type of voluntary grasping | —554 | +941 | |
| Spontaneous posture of the legs in vertical suspension | —454 | +941 | |
| Spontaneous motility of the legs | —490 | +913 | |
| Asymmetric tonic neck reaction, spontaneous | —510 | +910 | |
| Asymmetric tonic neck reaction, imposed | —520 | +902 | |
| Rooting | —438 | +824 | |
| Spontaneous posture of the arms | —650 | +797 | |
| Coordination of the upper extremities | —449 | +787 | |
| Sitting up | —382 | +686 | +411 |
| Acoustical orienting | —395 | +685 | +399 |
| Footsole response | —551 | +679 | |
| Palmar grasp reflex | —436 | +665 | +375 |
| Moro lift, abduction/extension | —478 | +646 | |
| Moro hit, abduction/extension | —668 | +636 | |
| Response to push against shoulder, sitting | —531 | +628 | |
| Posture during sitting | —492 | +502 | +506 |
| Following an object with eyes, head and trunk, sitting | —565 | | +591 |
| Rolling over from prone into supine position | —398 | +788 | |
| Duration of sitting | —479 | | +695 |
| Spontaneous motility of the arms | | | |
| Moro headdrop, adduction/flexion | | | |
| Moro lift, adduction/flexion | | | |
| Moro hit, adduction/flexion | | | |

velopmental rate and the moment of the final change are preprogrammed. These items reflect brain mechanisms underlying the development of locomotion in supine via prone into vertical position. Attention must be paid to the finding that isolated relationships between the first and the final change do not occur, as this implies that in no single instance is the development of an item dependent only on the developmental rate. For four items of Table XV no correlation-coefficients were computed. These items are the adduction/flexion components of the three types of the Moro reactions and the spontaneous motility of the arms. This was not done because the first changes of spontaneous motility of the arms occurred at the same time in the case of all infants; as for the adduction/flexion components of the Moro reactions in the majority of infants the first change consisted of a complete disappearance. In both instances the developmental range was similar to the final change, which precluded the computation of meaningful relationships.

From these patterns of relationships it can be concluded that, in the normal development of brain mechanisms underlying the responses elicited during the neurological examination, both the developmental rate and the moment of the last developmental change may be preprogrammed, often in combination with each other, while sometimes in the case of identical items various developmental strategies can be followed. These relationships are clinically important as they prove a prediction of the developmental range on the basis of the moment of the first developmental change to be impossible. This is mainly due to the preponderance of the relationships between the developmental range and the final change.

# Chapter XIV Inter-item relationships

In this chapter the possibility will be considered of formulating meaningful relationships between identical parameters of different items and of founding these relationships on a statistical analysis of the data. For the latter purpose Pearson Product Moment correlations were computed and matrices produced which made factor analysis feasible. As the sex differences were small, boys and girls were taken together. The distribution of the scores for the parameters could be considered as being sufficiently symmetrical for this purpose, except the distribution of inconsistencies (Appendix C), so that in this case Rankorder techniques (Spearman Rank) were used for the statistical analysis.

The items of the neurological examination can be grouped according to hypothetical subsystems of the nervous system, which reflect the brain mechanisms underlying the nervous functions assessed. In the developing nervous system such a distinction between subsystems is complicated by the fact that some brain mechanisms are a prerequisite for the expression of others. Before locomotion in prone or in vertical position can efficiently be carried out for instance, postural mechanisms and mechanisms for the maintenance of balance have to be eleborated. Before an infant can develop progression in prone position, he must be able to lift his head when lying in prone. Before he is capable of assuming a standing posture, he must develop balance mechanisms in order to be able to sit, while balance must be elaborated even more before he is able to walk without support. Development of sitting up should be preceded by the ability to lift the head in supine position and orientation of the head in space, and by the development of the ability to turn over from supine into prone position, i.e. mechanisms for differentiated rotation of the body.
For the development of independent goal directed manipulative activity differentiation of arm and hand motility is a prerequisite, and one might assume that mechanisms underlying palmar grasp reflex activity or asymmetric tonic neck reflex activity play an important rôle in the development of differentiated and voluntary use of the arms and hands. This would mean that the palmar grasp reflex and the asymmetric tonic neck response would diminish previously to, or synchronously with, the development of arbitrary use of hands and arms, while at the same time visual mechanisms have to develop at a very early period in order to guide the manipulative behaviour.

Considering the proces of development particularly with a view to first developmental changes, one might assume a relationship between the first changes of sitting, standing and walking and other items dealing with the brain mechanisms involved in this type of motor behaviour, i.e. postural mechanisms and balance. Thus there might be a cluster consisting of the first changes of sitting, walking and standing, placing reactions, footsole response, rolling into prone and back, head lift in supine position, posture in prone position and locomotion in prone.

There might also be a cluster of the first changes of items dealing with the development of manipulative i.e. goal directed motor behaviour, involving the palmar grasp reflex, type of voluntary grasping, coordination of the upper extremities, goal directed motility of the arms and hands, and asymmetric tonic neck responses.

Relationships between the first changes cannot be expected for all the items. Items such as speech, rooting and acoustical orienting cannot easily be fitted into other groups of items. One may expect the first changes of the Moro responses to be related, as they reflect developmental changes in one mechanism, but a relationship with other items is not likely, except in the case of spontaneous motility of the arms.
As for the moment of the last developmental changes (i.e. the final changes) analogous clusters of items may be assumed to exist; within these clusters subgroups may be found (for instance balance during sitting, motor behaviour in prone position, motor behaviour while standing) reflecting the differentiation of the developing brain mechanisms for posture, balance and locomotion. As stated above, relationships between the first changes and relationships between final changes would not be unexpected as these parameters indicate the maturation of brain mechanisms on the time scale. As was explained above, some brain mechanisms must have developed before others can start to achieve expression. These relationships may be relatively low due to the variability in development characteristic for a normal nervous system; still, they should not be neglected.

As for the developmental rate, expressed in the length of the developmental range, relations cannot be predicted so easily. The developmental rate of brain mechanisms may vary considerably dependent on the degree to which the first and/or the final change are fixed. As has been shown in chapter XIII, the interdependency of the developmental rate and the moments of the first and the final changes is very complex, intra- as well as inter-individually.
Therefore one may assume the number of relationships between items with regard to the developmental range to be small, and the relationships, if present, rather low.

The statistically significant relationships ($p < 0.01$) between first changes, final changes and developmental ranges respectively are presented in appendices E, F. and G.

**First change**

As for the first change (Appendix E) a cluster of items can be observed which concern sitting, crawling, standing and walking. Rolling and the optical placing reaction of the feet are also included in this cluster: the footsole response, however, is not. On factor analysis it appears that this group of items accounts for 22% of the variance of the material.
Other large clusters are not evident. As for the items dealing with the development of manipulative motor activity, clustering is merely reflected by the interrelations of the coordination of the upper extremities,

goal directed arm and hand motility, and type of voluntary grasping. The first change of the palmar grasp reflex is conspicuously absent in this small cluster, which means that a decrease of palmar grasp reflex activity is not a prerequisite for the development of goal directed and manipulative motor activity of the arms and hands. As was to be expected, the relationships are rather weak, with the exception of the interrelationships of items dealing with sitting behaviour, which, however, are contaminated as a result of their operationalization. There is a strong relationship between standing and walking; this is not surprising as both items reflect the conclusion of developmental sequences in connection with the maturation of postural and balance mechanisms in infancy. In this carefully selected group of low risk infants, which is also rather homogeneous with regard to environmental and social conditions, the majority of the weak (although statistically significant) relationships illustrate the variability of the healthy nervous system.

In the case of nine items there were no interrelationships of the first changes. (Table XVI). Neither speech nor acoustical orienting showed a significant relationship with any other item. These items can be regarded as belonging to a separate category, in which mental processes are involved, different from the sensorimotor development represented by the other items.

**TABLE XVI**

**Items without any significant relationships ($p \leqq 0.01$) with regard to first changes.**

vocalization and speech
acoustical orienting
spontaneous posture of the legs in vertical suspension
spontaneous head lift in supine
sitting up
foot sole response
palmar grasp reflex
parachute reaction of the arms
Moro hit abduction/extension

The absence of significant and meaningful relationships between responses like the palmar grasp reflex, the footsole response and the Moro reactions on the one hand and functional motor development on the other hand implies that it is hardly possible to predict the onset of the development of motor functions on the basis of changes as in these reactions. The absence of a significant relationship between the first change of the palmar grasp reflex and the first occurrence of voluntary grasping ("palmar grasp type") or of functional arm/hand motility ("looking at and playing with the hands") suggests that the dissolution of the former does not affect the development of the latter to a large extent.

**Final change**

As Appendix F shows there were many interrelationships between the final changes with rather low correlation-coefficients. The group of items dealing with gross motor functioning (crawling, sitting, standing and walking) appears as a major cluster; this cluster reflects the integration of postural mechanisms and balance with voluntary gross motor activity during maturation.
The highest correlation-coefficients are found in the relationships between fully developed balance reactions (the items "following of an object with the eyes, and rotation of the head and trunk during sitting" and "response to push against the shoulder during sitting") and steady sitting (the items "sitting up", "posture during sitting" and "duration of sitting"). The items "standing up", "walking", "posture of the legs in vertical suspension", "optical placing of the feet", "prone position" and "locomotion in prone position" belong also to this cluster, the height of the correlation coefficients varying. It is not surprising that the final score for "spontaneous motility of the legs" (i.e. voluntary and arbitrary motility) is included in this cluster. "Head lift in supine position" and the quality of the footsole response can be considered to contribute to this cluster in varying degrees. Also voluntary i.e. arbitrary rolling behaviour correlates with the majority of the items mentioned. On factor analysis this cluster is represented in one factor, accounting for 29% of the variance.

A smal cluster consists of the final changes (i.e. dissolution) of the Moro reaction, which is independent of the large cluster of voluntary motility. This small cluster accounts for another 10% of the variance.
In the section on the developmental course of the Moro reactions the significance of the low value of the correlation-coefficients has been discussed. There is no separate group of items assessing manipulative motor activity. Only an isolated relationship between the dissolution of the palmar grasp reflex and arbitrary arm/hand posture was found. This relation suggests an interplay between the development of arbitrary and independent use of arms and hands and the developmental course of the palmar grasp reflex. No relationship was found between the dissolution of the palmar grasp reflex and the mature type of grasping (pincer grasp).

The maturation of type of voluntary grasping and coordination of the upper extremities showed a relationship with the final change of sitting, standing and walking, which reflects the integration of brain mechanisms required for manipulative motor behaviour with brain mechanisms on which gross motor behaviour is based. There were only five items which did not have a significant relationship with any of the others. They are listed in Table XVII.
Among them are the items speech, acoustical orienting and, surprisingly, goal-directed motility of the arms and hands.

**TABLE XVII**

**Items without any significant relationships ($p \leqq 0.01$) with regard to final changes.**

vocalization and speech
acoustical orienting
goal directed motility of the arms
asymmetric tonic neck reaction, spontaneous
asymmetric tonic neck reaction, imposed.

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As mentioned above, speech and acoustical orienting may perhaps be regarded as belonging to a separate category when compared with "pure" sensorimotor development. To some extent the same can be said of the development of goal directed motility of the arms and hands.

Several authors have reported that the infant's development during the first year of life, which is appreciated mainly in terms of sensorimotor development, is related only weakly to the development in later life, which is mainly appreciated by "mental" criteria (Rutter (1970); Hindley (1960), Knobloch and Pasamanick (1963)). The finding that the three items speech, acoustical orienting and goal-directed motility of the arms and hands did not show any significant relationship with other items, is intriguing, as these items may partly reflect mental development. It would be worthwhile to explore their relation with the future mental development, while their interrelationships — which were appreciably low in the present study — should also be scrutinized.

It is noteworthy that the moment of a complete dissolution of the asymmetric tonic neck reactions did not show a significant relationship with any other item. Clinically, this finding is important, as after a certain age the presence of asymmetric tonic neck patterns is often considered as a sign of deviant development, or even as an early sign of the development of cerebral palsy. When the wide variation range of the dissolution of the asymmetric tonic neck reactions and its isolation with regard to interrelationships with other items, is taken into account, the clinical value of this single finding is rather small. Yet, pathological asymmetric tonic neck reflexes should be distinguished from the asymmetric tonic neck reactions normally present. Besides, in a pathological nervous system other relationships between (pathological) signs can be expected than in the case of a healthy nervous system.

### Developmental range

Appendix G presents the relationships between the developmental ranges, which are statistically significant ($p < 0.01$). Actually, the number of significant relationships is small. One small cluster of items can be observed with regard to sitting behaviour. As is stated above, however, the first changes in these items were contaminated due to their operationalization, which may account for part of the relationships between the developmental ranges. Moreover, it is evident that in these items comparable brain mechanisms are involved. There are no other evidently interrelated groups of items, which means that the developmental rate of various brain mechanisms is relatively independent and may vary considerably. From a clinical point of view this means that in normal infants no prediction can be made with regard to the developmental rate of one nervous function on the basis of the developmental rate of another nervous function. This is illustrated by the clinically well known fact that in some infants some nervous functions appear to develop faster than others, while the opposite may happen in other infants. In damaged infants, however, a prediction of the developmental rate can often be made on the basis of findings reflecting particular deviant brain mechanisms. Variability in developmental rate can be considered as an individual characteristic of healthy infants, while in damaged infants this variability may be lost.

Eleven items of the total number of thirty-one did not show a significant correlation with any other item (Table XVIII). The negative (low) correlation-coefficient between the developmental range of speech and posture of the trunk during sitting can hardly be explained and may perhaps be attributed to accidental arithmetical coincidence. If we take this for granted, we find again that the three functional items "speech", "acoustical orienting" and "goal directed motility of arms and hands" do not show an evident coherence with the developmental range of other items.

**TABLE XVIII**

**Items without any significant interrelationships ($p \leqq 0.01$) with regard to developmental ranges.**

acoustical orienting
goal-directed motility of the arms
vocalization and speech
spontaneous motility of the arms
spontaneous posture of the legs
rolling from supine into prone position
rolling from prone into supine position
walking
palmar grasp reflex
asymmetric tonic neck reaction, spontaneous
asymmetric tonic neck reaction, imposed
Moro headdrop, abduction/extension

### Inconsistencies

Inconsistencies were defined as relapses in score, irrespective of the length of the period of time during which the relapse occurred. This means that if the scoring-scale of the individual items is assumed to reflect the development of the item responses in time, there is a regression to a previous type of response, i.e. belonging to a younger age. In the majority of instances such a regression was observed during one examination only; it was often found that at the following assessment the infant exceeded the score that he had obtained before the regression, i.e. he had caught up completely.

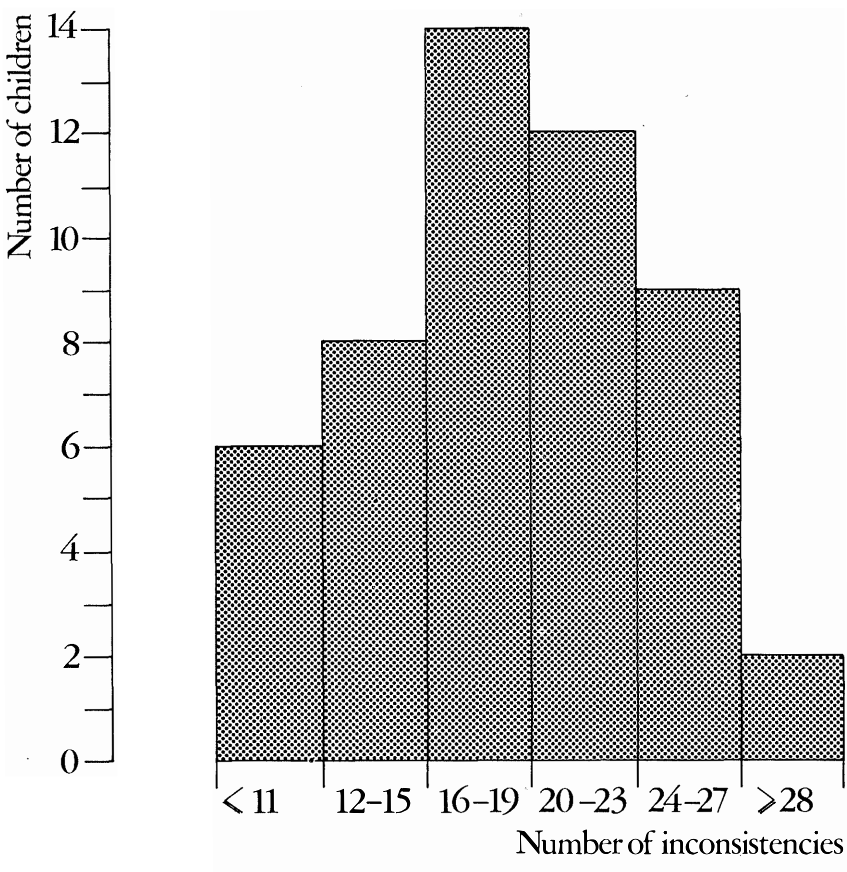


Fig. 46:

The frequency-distribution of the total number of inconsistencies, occurring in all items of group III taken together.
Vertical axis: number of infants with inconsistencies.

**TABLE XIX**

**The number of inconsistencies and the number of infants with inconsistencies of the items of group III.**
**The items are ordered according to the number of inconsistencies pro item, and, within these groups, according to the number of infants displaying inconsistencies.**

| Name of item | Number of infants with inconsistencies | Total number of inconsistencies |
|---|---|---|
| Standing up | 2 | 2 |
| Walking | 2 | 2 |
| Response to push, sitting | 4 | 4 |
| Acoustical orienting | 6 | 6 |
| Spontaneous motility of the arms | 7 | 7 |
| Duration of sitting | 7 | 7 |
| Vocalization and speech | 8 | 8 |
| Optical placing reaction of the hands | 8 | 8 |
| Following of an object with the eyes, head and trunk, sitting | 9 | 9 |
| Rolling over from supine into prone | 4 | 5 |
| Spontaneous head lift in supine | 6 | 7 |
| Posture of the trunk, sitting | 10 | 11 |
| Palmar grasp reflex | 12 | 13 |
| Moro, headdrop, adduction/flexion | 11 | 13 |
| Spontaneous posture of the arms | 12 | 13 |
| Optical placing reaction of the feet | 14 | 16 |
| Asym. tonic neck response, imposed | 17 | 18 |
| Moro, headdrop, abduction/ext. | 19 | 20 |
| Type of voluntary grasping | 21 | 22 |
| Goal-directed motility of the arms | 22 | 24 |
| Rolling over from prone into supine | 12 | 15 |
| Locomotion in prone | 23 | 27 |
| Sitting up | 26 | 31 |
| Spontaneous motility of the legs | 24 | 36 |
| Coordination of the upper extr. | 27 | 36 |
| Moro, hit, abduction/extension | 28 | 37 |
| Rooting | 29 | 54 |
| Moro, lift, adduction/flexion | 30 | 37 |
| Asym. tonic neck response, spont. | 30 | 38 |
| Moro, lift, abduction/extension | 32 | 46 |
| Parachute reaction of the hands | 33 | 48 |
| Spontaneous posture of the legs | 38 | 52 |
| Moro hit, adduction/flexion | 38 | 59 |
| Footsole response | 39 | 79 |
| Posture of head, trunk and arms in prone position | 40 | 59 |
| Spontaneous posture of the legs in vertical suspension | 48 | 113 |

Fig. 46 shows the frequency distribution of the total number of inconsistencies which occurred in the items of group III in the total group of infants (see also Appendix J). The peak frequencies are found between sixteen and twenty-three inconsistencies; in six infants eleven inconsistencies occurred, and in two infants twenty-eight or twenty-nine inconsistencies were found. However, the eleven inconsistencies which occurred in six infants were not identical. Although it was possible to order the items of group III according to the number of inconsistencies occurring during development (Table XIX), and to order the infants according to their tendency to display inconsistencies, there was no relationship between infants and items. For instance, in some of the six infants who had eleven inconsistencies, inconsistencies appeared in items in which no inconsistencies were found in the case of the two infants who showed most inconsistencies. There was no single infant without any inconsistency in one item or another, neither were there any infants who showed inconsistencies in all the items.

How can inconsistencies be accounted for?

1. Inconsistencies may be due to problems of standardization and operationalization. Although for the majority of reflexes and reactions the developmental sequence of response-patterns could be defined beforehand, for spontaneous motility and posture this sequence had to be defined on the basis of the observations. Thus one might expect the number of inconsistencies be larger in the case of spontaneous motility and posture. Table XIX shows that this is not always the case. The number of inconsistencies in for instance the item "spontaneous motility of the arms" is low, while it is much larger in the item "spontaneous posture of the legs in vertical suspension". The number of inconsistencies during the development of for instance the footsole response or the rooting reflex is also considerable, while it is much smaller in for instance the palmar grasp reflex.

2. It is possible that the number of inconsistencies increases on a parallel with the developmental range. Actually the occurrence of an inconsistency, i.e. a relapse in score, postpones the moment of the final change and thus prolongs the developmental range. Consequently the length of the developmental range cannot account for the occurrence of inconsistencies. Only in the case of a fixed developmental range, i.e. a close relationship between first and final change, the inconsistencies cannot prolong the developmental range. Such exclusive relationships were not found in the present group.

   Appendix H presents the correlation-coefficients (Spearman Rank Correlations) of statistically significant relationships ($p < 0.01$) between the number of inconsistencies and the developmental ranges. In twelve items such a relationship was found. The majority of the items concerns responses which during their developmental course gradually merge into voluntary motility (e.g. placing and parachute

reactions, rooting, asymmetric tonic neck response). Some others are activity-or state-dependent, such as the Moro reactions which are easily inhibited by voluntary motor activity. In the case of the few instances of "spontaneous" motor behaviour (rolling, type of voluntary grasping and coordination of upper extremities) the occurrence of inconsistencies may also be state dependent. Therefore, rather than merely dependent on the length of the developmental range, it is very well possible that the inconsistencies depend on the behavioural state of the infant during the assessment.
The occurrence of inconsistencies, which may cause a prolongation of the developmental range, may also reflect the strain under which the neurons operate. Thus the inconsistencies would reflect relapses of neuronal functioning, as a result of temporary failing during the maturation of brain-mechanisms.

3. McGraw (1943) drew attention to the fact that the various consecutive phases of the development of functions reflecting "neuromuscular maturation" showed considerable overlap. This means that during one single examination responses can be obtained which belong to various developmental phases. Consequently a response obtained at a particular assessment may be accidental to a certain extent, as the infant can display various responses at one particular age, i.e. during one single assessment. McGraw showed that this overlap of phases could extend over weeks or months. If seen in this context, the inconsistencies may be considered as artificial, i.e. depending on the (accidental) moment of examination and observation.

4. Finally, the inconsistencies may reflect the qualitative variability of the nervous system during development. The data of figure 46 and Table XIX suggest that the occurrence of inconsistencies is characteristic of both individual items and individual infants, without an evident relationship between these two characteristics. Therefore the presence of inconsistencies may also be considered as resulting from the variability proper to the healthy organism.

Theoretically, no specific clusters of items can be expected with regard to the occurrence of inconsistencies. Moreover, the variability of their occurrence pro item and pro infant is so large and unsystematic that a computation of relationships would hardly give any meaningful results. This is confirmed by the rank order correlation (Spearman Rank Correlation). There were low, but isolated relationships between about half of the items, but a systematic coherence was not found. It appears that the occurrence of inconsistencies depends on the type of item; furthermore they appear to occur more or less randomly.

The practical consequence of the occurrence of inconsistencies is considerable, because they indicate that the results of a single assessment cannot be regarded as reflecting the proper neurological condition of an infant unequivocally.

# Chapter XV Discussion and conclusions

The nervous system can be considered as an information processing apparatus which consists of a complex set of brain mechanisms. To quote Prechtl (1970): "It (i.e. the nervous system) receives, conducts, transforms, compares and generates messages. In the developing nervous system the operations of the nervous system at each developmental stage are adapted, as a result of the historical processes of evolution, to the internal and external conditions of the organism". In this connotation a brain mechanism is defined as a network of neurons and synapses, which consists of subroutines for specified nervous activity. Using terms from computer technology, once can say that a brain mechanism (or neural mechanism) presupposes the presence of "hard-ware", and at the same time implies operative "soft-ware". One may gain insight in the organization of these mechanisms during their maturation by studying the developmental changes occurring in their (motor) output.

The question arises whether maturation and organization of neural mechanisms take place in accordance with a fixed time-schedule, as happens in motor behaviour, which in general develops according to a rather regular sequence. If this were the case, neural mechanisms required for functions which develop early, would mature first and in due course they would be followed by mechanisms needed for functions which appear later. This view has been forwarded by Anokhin (1964). It is also possible that the various neural mechanisms mature with wide overlap, or even synchronously, but that their output becomes apparent in a more or less fixed sequence of time, dependent on the period of time needed for the integration or linking together of previously separate modules. Finally, there may be a combination of these two processes. In this connotation the term "maturation" means the structural cq. morphological changes which occur in the nervous substrate during ontogeny and which are based on an intricate interplay between genetic and environmental factors. In order to answer the question mentioned above, a set of items has been selected belonging to the neurological assessment during infancy, which describe the developmental expansion of the infant's neurological repertory.

The items could be divided into four groups.

The first group contains those items which did not show any substantial changes from birth onwards. The second group contains items which developed rapidly. The third group contains items which showed a protracted but distinct developmental course, while in the fourth group are placed those items which showed either an indistinct developmental course, so that a final predefined limit of development could not be determined unequivocally, or a protracted development exceeding the period of the follow-up, which, for practical reasons, was ended at the milestone of walking free.

The items of group I did not show any notable changes from the first examination onwards. From this one may conclude that their neural mechanisms are sufficiently mature at birth. These mechanisms can be seen as basic for the further developmental differentiation of nervous functioning.

As for the items of group II, which showed a rapid developmental course, their final stabilization took place after a short period of time. This means that their neural mechanisms mature rapidly. These items can be considered to be based on neural mechanisms which form an elaboration and expansion of the mechanisms of the items of group I.

Undoubtedly, the functional expression of these mechanisms is of primary importance for the infant's subsequent development. To give an example, the items dealing with the visual apparatus reflect a functional differentiation of this apparatus which is a prerequisite for an adequate development of motor patterns like grasping, sitting, crawling and walking.

Thus group I and II represent neural mechanisms whose maturation must take place before other mechanisms can properly manifest themselves, and which may even be considered as a prerequisite for the maturation of the latter. This does not imply that neural mechanisms for e.g. grasping or progression in prone position cannot develop when the neural mechanisms underlying visual functions for instance are deficient. It is a well-known fact that blind infants develop grasping and crawling patterns. However, these motor patters develop differently from those in infants with a well developed vision. This example illustrates the moulding effect of one neural mechanism, or of the expressions of one mechanism, on the subsequent development of other mechanisms.

A special remark must be made about the "stepping movements" of the very young infant. This motor pattern, based on a spinal coordination mechanism, disappears in the first months of life but reappears at walking age. It seems highly improbable that the neural mechanism which is responsible for the stepping movements dissolves completely, only to reappear at a later age. It is more likely that this mechanism becomes dominated by mechanisms underlying other motor patterns, such as symmetrical and asymmetrical flexion and extension movements of the legs, which appear at about the age when the "stepping movements" vanish (cf. fig. 7, 9, 10). During this period of domination of the original spinal mechanism by other mechanisms (which serve the differentiation of leg motility), the spinal mechanism is incorporated in more complex mechanisms which finally results in voluntary and variable walking patterns. It goes without saying that also the mechanisms for asymmetrical and symmetrical leg motility which temporarily replace the stepping pattern, are incorporated in this final organization of brain mechanisms for walking.

As for the items of group III and IV, which showed a protracted developmental course, generally their final stabilization takes place after a considerable period of time. Some items of group IV had not yet become stabilized at the close of the follow-up.

The remainder of the items of group IV, i.e. the items which reached their final stabilization before the moment of walking free, gradually merged into voluntary motor patterns, so that it was impossible to indicate the moment of final stabilization on the time-scale. This was not the case with the items of group III, for which an evident final change or final stabilization could be defined. Thus the neural mechanisms which achieve expression in the items of these two groups, show a protracted developmental course, which is not necessarily finished at the age of walking free (this confirms the arbitrariness of the age of walking as the end of the follow-up (cf. chapter II)). During this developmental course various processes take place. In some items the gradual development of a motor behaviour into its final form suggests a smooth and slow integration of its underlying neural mechanism into more complex mechanisms. This is for instance the case with tactile placing of the feet or the positive supporting reaction. In others there is a more abrupt change of response-type, as happens, for instance, in the items describing the maintenance of balance (e.g. response to push during sitting) and the optical placing reactions. Their underlying mechanisms seem to achieve expression as soon as they have matured sufficiently, irrespective of their rate of maturation.

In other items different brain mechanisms seem to be involved in the final stabilization. In this connection it is noteworthy that the final changes of sitting up, standing and walking are closely correlated. As long as these motor activities need external support, their neural mechanisms mainly consist of the regulation of active power. In sitting up, standing or walking independently neural mechanisms for the maintenance of balance must be involved. The development of equilibrium reactions, such as response to push against the shoulder, or visual following an object with rotation of head and trunk during sitting, shows that the maturation of neural mechanisms for balance takes place at about the same time as the maturation of the neural mechanisms for the motor programmes required for sitting up with help. Here is an example of various modules which develop more or less independently from each other at about the same time, but which are later linked together.

While in the case of the items of group I and group II there seems to be a time sequence in the maturation of brain mechanisms, in the case of many items of group III and IV there seems to be a contemporary maturation of brain mechanisms which may achieve expression consecutively. The dissolution of the palmar grasp reflex for instance takes place at about the same time as the beginning of the development of voluntary grasping, which might imply that a dissolution of the palmar grasp reflex is a prerequisite for the development of voluntary grasping. Yet the findings show that a palmar grasp reflex and the initial type of voluntary grasping may coincide; the relationship between the dissolution of the former and the first appearance of the latter was appreciably low. Thus the neural mechanisms on which these items are based may operate at the same time without being causally related.

If brain mechanisms mature independently during the same period of time, it may be argued that the morphological maturation of various parts of the nervous system also takes place independently. This hypothesis is supported by an analysis of the later phases of the development of voluntary grasping, i.e. the sequence of scissor-type via inferior pincer-type and pointing, to pincer-type. This type of voluntary grasping represents differentiated use of the hand and fingers, i.e. fine manipulative motor activity; it is a cortical function, while the other types of grasping are of non-cortical origin (see page 56). The phase of "pointing" appears to be a rather incapacitating and upsetting period of development for many infants, in which obviously other grasping-types do not occur. It can be regarded as the period during which the various modules are linked together. If this hypothesis is correct — experiments with rhesus monkey infants point in this direction — the development of voluntary grasping is an illustration of the independent maturation of brain mechanisms because their underlying neural structures develop relatively independently of each other.

As for the question raised at the beginning of this chapter, at least three types of neural mechanisms can be distinguished. Firstly there are those mechanisms which are present at a very early stage of the infant's development. They are regarded as a prerequisite for further development. Examples are the neural mechanisms for visual and acoustical perception and the mechanisms for the generation of adequate muscle tension. They can be labelled "primary" or "basic" neural mechanisms.

Secondly, there are those neural mechanisms which gradually merge into larger and more complex mechanisms, or wich seemingly disappear completely and reappear in another from at a later phase of development (e.g. stepping movements and voluntary walking patterns). They may reappear at periods of a break-down of the organism (e.g. reappearance of "infantile response" - like reactions in deteriorating patients). These mechanisms seem to mature according to a rather regular sequence. Thirdly there are the mechanisms which mature more or less independently and become linked together at a particular moment, which process results in differentiated motor patterns (e.g. the development of voluntary grasping, ending with the pincer grasp and the development of independent sitting-up, standing and walking).

One might expect some particular neural mechanisms to disappear during ontogeny, because they lose their functional significance after a particular phase of development. Certainly the functional expression of some early neural mechanisms disappear, as for instance the palmar grasp response, the Moro reactions and rooting. Milani-Comparetti contends that such a disappearance is a prerequisite for development of other specific motor patterns. The palmar grasp reflex for instance must have disappeared before an infant is able to support himself on his (opened) hands in prone position. The plantar grasp reflex should have disappeared before an infant is able to stand up, and likewise the Moro reactions must have dissolved before parachute-reactions or placing reactions occur (Milani-Comparetti and Gidoni, 1967). The prediction bands for the developmental courses of these items suggest that the relationships as postulated by Milani-Comparetti are weak, if present at all. On computation no significant correlations were found.

This is not surprising, as the emperical finding that some "infantile responses" wane at an age at which differentiated motor behaviour has not yet developed but starts to do so, does not imply a causal relationship between these two sets of phenomena,

Moreover, it is questionable whether the neural mechanisms themselves disappear. The number of synapses changes considerably during development; consequently the functional manifestations of neural mechanisms also change during development. A definite and total disappearance of neural mechanisms, however, would imply a thorough rearrangement of neural connections to such an extent that the original pattern would no longer be recognizable. This seems hardly compatible with an efficient maturation of a complex system which has to fullfil present functional demands and at the same time must increase in differentiation and complexity in order to fullfil future demands. (cf. Eccles, 1973).

Clinical experience as wel as research reports support the view that neural mechanisms do not disappear definitely and totally.

It is a well-known clinical experience that in some deteriorating diseases, or in cases of serious brain damage, motor patterns may become manifest which closely resemble patterns known from infancy, such as sucking responses, grasp reflexes etc. (Paulson and Gottlieb, 1968). Thus we may assume that during ontogeny some neural mechanisms seem to disappear because they become dominated or covered by other mechanisms or because they expand or are combined with other mechanisms, without losing their characteristics. This explains their reappearance at later ages under specific circumstances.

However, the functional display of such neural mechanisms does not disappear in all instances. For instance the tonic neck responses seem to disappear during development. Apart from their reappearance under pathological circumstances, which shows that their neural mechanisms do not dissolve, they can be observed also in non-pathological conditions (i.e. in healthy individuals) if proper examination techniques are applied. Frankstein et al (1972) demonstrated their presence in the respiratory muscles of healthy adults by means of electromyographic recordings. A change of the position of the head (rotation as well as tilting) modifed the tonus of the respiratory chest muscles. Wells (1944) reported similar findings for the limb-musculature in normal humans. Another example of a seemingly definite change of a motor programme is the Babinski response, which under normal conditions disappears during ontogeny as is described in the present study, but which can still be elicited in normal adults during sleep (Battini et al. 1965).

The so-called "infantile responses and reactions" such as the grasp-reflexes, the Moro reactions, the stepping movements, the Bauer reaction etc. should be considered as a display of neural mechanisms which belong specifically to the very young nervous system. Their changes reflect the organization of the brain during development, whatever their functional meaning in a teleological sense may be (or may have been). For their functional display the neural mechanisms utilize similar final common pathways as other more differentiated mechanisms will do at a later stage of development. Moreover, it is possible (and in some instances probable, for example stepping and crawling movements) that the mechanisms themselves may be "utilized" by mechanisms which develop later. In this view they may be regarded as preparatory for future development, but there need not be a causal relationship between the dissolution of their functional display and the genesis of later motor behaviour. During ontogeny they will become latent as a result of the development of subsequent mechanisms, but they may be "taken up" again if needed. The development of such "dominating" mechanisms plays a significant role in this process. If in damaged organisms these "dominating" mechanisms fail to develop properly, it is conceivable that the development of the final differentiated motor behaviour may be hampered. For instance if the palmar grasp reflex fails to dissolve, i.e. if the neural mechanism for the palmar grasp reflex is not properly dominated by mechanisms for voluntary motor behaviour of the hands and the fingers, it is not surprising that this will disturb the proper development of type of voluntary grasping (i.e. a specific type of voluntary use of the fingers). In a similar way, the persistance of an asymmetric tonic neck reflex (resulting from a deficient development of dominating mechanisms for flexion/extension patterns of the arms or legs) may result in a defective development of goal-directed motility of the arms and hands or of voluntary sitting or walking.

In the beginning of this chapter it was argued that in general the functional development of the human infant takes place according to a regular sequence. This means that one can observe a gross outline of developmental sequence, in so far as particular functions must have developed before others achieve expression. This is not contradicted by the fact that there may be great variability in details, inter- as well as intra-individually. For instance, an infant must be able to lift his head in supine position before he is capable of sitting up, and the majority of infants are able to sit up before they can asume standing posture. However, this is not always the case. In our group some infants developed the ability to stand before they were able to sit up independently. Another example is the common experience that many infants are able to sit without support for a considerable period of time before they can sit up independently, or that some infants do not crawl at all before walking free.

The differences between boys and girls, however slight, with respect to the development of different motor patterns also indicates the inter-individual variability. In this case it may be caused by endocrine influences. Flechsig's (1927) opinion that girls develop faster than boys in all functional areas as a result of a generally advanced myelination in the case of the girls, is contradicted by the finding that the differences between the boys and the girls of the present group were variable with regard to various functional areas.

Besides a variability in the sequence of the development of motor functions, the rate of development may vary widely. In one and the same infant various motor patterns may respectively develop rapidly or slowly;

they may also start to develop early or late, while one and the same motor pattern may develop rapidly or slowly, cf. early or late, in different infants.
Apparently there is a kind of blueprint of development characteristic for each individual infant, with possibly a great variety in details. This may result in a genetically determined variability in development (Scott '57). However little may be known about the contribution of innate and environmental factors to the development of an infant, it is evident that there is an intricate but variable interplay between these two as is discussed for instance by Bekoff and Fox (1972).
Another example of the intra -and interindividual variability during development is the occurrence of inconsistencies. The frequency with which these occur appears to be characteristic for individual infants as well as for particular items. As is discussed in chapter XIV, in some infants particular items tend to show many inconsistencies during their developmental course; at the same time other infants show many inconsistencies during consecutive assessments, but definitely not in all items. It was postulated that the occurrence of inconsistencies can be considered as a characteristic of a normally developing nervous system.

Finally a few remarks will be made about the practical implications of the findings of the present study.

1. The items of group I and II can be considered to reflect the integrity of basic neural mechanisms which are a prerequisite for adequate neurological development during infancy. Therefore they would appear to be of clinical significance for a neurological assessment.
2. The items of group III would appear to be of clinical siginificance in so far as they reflect the qualitative development of neural mechanisms; these, however, show a developmental course which may vary widely interindividually.
3. From a strictly developmental point of view, the items of group IV seem hardly useful, as their variability is large and in some instances their developmental course is protracted excessively. For a neurological assessment they are useful only in the case of evident and consistent qualitative deviations from normal responses, such as evident left-right differences in motor performances.
4. It is not advisable to use isolated motor performances as indicators for neurological development and neurological integrity, due to the large variability of the developmental rate of the various items and the low relationships between the majority of them. An evaluation of the neurological development as well as the neurological integrity can only be made by means of a comprehensive assessment of the infant.
5. As a consequence of the large developmental variability intra- as well as inter-individually, it is hardly possible to label an infant as an "early or a late developer" or as a "rapid or slow developer".
   Milestones in the infant's functional development are of limited value from a neurological and developmental point of view.

6. The regular occurrence of inconsistencies illustrates the small value of one single assessment. For an adequate evaluation of the neurological development and of the neurological integrity of an infant, repeated assessments are needed.

*"And being now at some pause, looking back into that I have passed through, this writing seemeth to me, si nunquam fallit imago, (as far as a man can judge of his own work) not much better than that noise or sound which musicians make while they are tuning their instruments: which is nothing pleasant to hear, but yet is a cause why the music is sweeter afterwards".*

*Francis Bacon (1605)*

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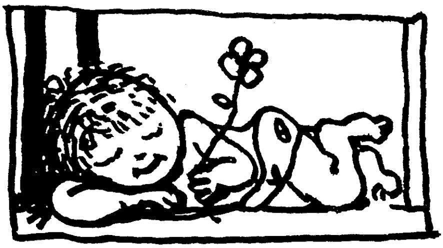

**Appendix A:** Criteria for optimal obstetrical conditions (adapted from Prechtl, 1968).

| | |
|---|---|
| maternal age | 18-35 years |
| marital state | married |
| parity | 1-6 |
| abortions in history | 0-2 |
| pelvis | no disproportion |
| luetic infection | absent |
| Rhesus antagonism | absent |
| blood group incomptability | absent |
| nutritional state | well nourished |
| anaemia | absent |
| bleedings during pregnancy | absent |
| infections during pregnancy | absent |
| X-ray abdomen during pregnancy | no |
| toxaemia of pregnancy | absent or mild |
| blood pressure | not exceeding 140/85 |
| albuminuria and oedema | absent |
| intra uterine position | vertex |
| psychological stress | absent |
| prolonged unwanted sterility (2 years) | absent |
| hyperemesis | absent |
| maternal chronic diseases | absent |
| gestational age | 38-41 weeks |
| twins or multiple birth | no |
| delivery | spontaneous |
| fetal presentation | vertex |
| drugs given to mother | $O_2$, local anaesthetic |
| duration first stage | 6-24 hours |
| duration second stage | 10 minutes - 2 hours |
| contractions | moderate or strong |
| cord around the neck | no or loose |
| onset of respiration | within first minute |
| treatment, resuscitation | no |
| birth weight | 2500-4000 gr. |
| body temperature | normal |
| drugs given | nil |

Appendix B: Criteria for neonatal neurological optimality (according to Prechtl and Beintema, 1964).

| | |
|---|---|
| Resting posture: | symmetrical; flexion, semiflexion |
| Facial innervation: | symmetrical during rest and movement |
| Tremor, frequency: | no tremor, or tremor with high frequency ($\geqq$ 6/sec) |
| Tremor, amplitude: | no tremor, or tremor with low amplitude ($\leqq$ 3 cm) |
| Posture in supine position: | symmetrical; semiflexion of the extremities |
| Spontaneous motility: | alternating movements |
| Intensity of spontaneous motility: | medium intensity |
| Athetoid movements: | medium intensity in the fingers and toes |
| Deviant motility: | absent |
| Fontanelles: | normal range and consistency |
| Spontaneous eye movements: | occasionally conjugated |
| Nystagmus: | absent |
| Pupillary reactions: | present and symmetrical |
| Optical blink: | brisk |
| Muscle consistency: | moderate |
| Motor apparatus: | medium resistance against passive movements; moderate active power; range of movements normal |
| Abdominal skin reflex: | present and symmetrical |
| Biceps tendon reflex: | brisk and symmetrical |
| Knee jerk: | brisk and symmetrical |
| Rooting: | present in four directions |
| Sucking: | powerful and regular |
| Jaw jerk: | present |
| Palmar grasp: | symmetrical; medium intensity |
| Plantar grasp: | symmetrical; medium intensity |
| Posture of the arms during traction test: | flexion of the elbows |
| Head control: | present during 4-10 seconds |
| Foot sole response: | evident and symmetrical dorsiflexion of the big toe |
| Withdrawal reflex: | present and symmetrical |
| Magnet response: | present |
| Crossed extension reflex: | present and symmetrical |
| Asymmetric tonic neck reflex: | symmetrical if present |
| Moro threshold: | medium |
| Moro abduction, arms: | symmetrical; medium |
| Moro extension, arms: | symmetrical, medium |
| Headlift in prone position: | present during 3-10 seconds |
| Spontaneous crawling movements: | present and symmetrical |
| Galant response: | present and symmetrical |
| Posture in prone suspension: | head in one line with trunk |
| Tactile placing of the feet: | present and symmetrical |
| Stepping movements: | present and symmetrical |
| Crying: | normal pitch |
| State changes: | absent, or mild and easily influenced |

**Appendix C:** Means, standard deviations and coefficients of skewness and kurtosis for the items of group III, including speech development (total group).

| | First change | | | |
|---|---|---|---|---|
| | Mean | sigma | Skewness | Kurtosis |
| **Observation of posture and motility** | | | | |
| Spontaneous posture of the arms | 2.60 | 0.904 | 1.711 | 5.95 |
| Spontaneous posture of the legs | 2.26 | 0.527 | 1.899 | 5.72 |
| Spontaneous motility of the arms | 2.00 | c | c | c |
| Spontaneous motility of the legs | 2.90 | 0.763 | 0.446 | 2.65 |
| Spont.mot. of the legs in vert.suspension | 2.74 | 0.777 | 1.008 | 3.91 |
| Goaldirected motility of the arms | 3.22 | 0.545 | 0.107 | 2.80 |
| Type of voluntary grasping | 4.48 | 0.677 | 0.272 | 2.81 |
| Coordination of upper extremities | 6.62 | 1.067 | -0.215 | 2.61 |
| Post. of head, trunk, arms in prone position | 3.50 | 0.814 | 0.000 | 2.51 |
| Locomotion in prone position | 7.18 | 1.257 | 0.030 | 3.92 |
| Rolling over from supine into prone position | 6.74 | 1.352 | 0.382 | 3.64 |
| Rolling over from prone into supine position | 6.90 | 1.488 | 0.023 | 2.99 |
| Spontaneous head lift in supine position | 7.20 | 1.294 | -0.149 | 2.89 |
| Sitting up | 6.18 | 1.380 | 0.660 | 3.33 |
| Duration of sitting | 9.24 | 1.636 | 0.428 | 2.48 |
| Posture of the trunk during sitting | 9.20 | 1.629 | 0.389 | 2.48 |
| Standing up | 12.30 | 1.502 | 0.391 | 3.01 |
| Walking | 13.48 | 2.073 | 0.536 | 3.13 |
| **Reactions and Responses** | | | | |
| Rooting | 8.58 | 1.162 | 0.238 | 2.03 |
| Asym. tonic neck response, imposed | 2.06 | 0.580 | 0.623 | 4.91 |
| Asym. tonic neck response, spontaneous | 2.00 | 0.600 | 0.561 | 4.72 |
| Palmar grasp reflex | 5.68 | 1.058 | -0.690 | 2.97 |
| Reaction to push against shoulder d.sitting | 9.22 | 1.682 | 0.403 | 2.33 |
| Follow.an obj. with eyes head and trunk d.sitting | 9.28 | 1.642 | 0.382 | 2.42 |
| Optical placing of the hands | 8.26 | 1.065 | -0.022 | 3.13 |
| Parachute reaction of arms and hands in prone susp. | 9.96 | 1.678 | -0.041 | 4.14 |
| Optical placing reaction of the feet | 11.58 | 1.617 | 0.410 | 3.35 |
| Footsole response | 8.70 | 2.435 | 0.045 | 4.06 |
| Acoustical orienting | 4.92 | 0.752 | -0.162 | 2.47 |
| Moro headdrop, adduction/flexion | — | — | — | — |
| Moro headdrop, abduction/extension | 2.50 | 0.789 | 1.385 | 3.88 |
| Moro lift, adduction/flexion | — | — | — | — |
| Moro lift, abduction/extension | 5.76 | 1.661 | -0.450 | 2.78 |
| Moro hit, adduction/flexion | — | — | — | - |
| Moro hit, abduction/extension | 4.28 | 1.629 | 0.256 | 2.27 |
| Vocalization and speech | 2.52 | 0.544 | 0.306 | 1.88 |

Appendix D Correlation coefficients ($p \leqq 0.01$) of the relationships between the first and the final changes of the items of group III, including speech development (total group) (Pearson Product-Moment Correlations)

| FRIST CHANGE / FINAL CHANGE | Spontaneous posture arms | Spontaneous posture legs | Spontaneous motility arms | Spontaneous motility legs | Goal-directed motility arms | Spontaneous motility legs in vertical susp. | Type of voluntary grasping | Coordination upper extremities | Posture in prone position | Locomotion in prone | Rolling supine into prone | Rolling prone into supine | Headlift in supine | Sitting up | Duration of sitting | Posture, sitting | Standing up | Walking | Palmar grasp reflex | Footsole response | Asymmetric tonic neck response spontaneous | Reaction to push, sitting | Following object, sitting | Optical placing, hands | Parachute reaction, hands | Optical placing, feet | Moro, headdrop, abduction/ext. | adduction/flexion | Moro, lift, abduction/ext. | adduction/flexion | Moro, hit, abduction/ext. | adduction/flexion | Rooting | Acoustical orienting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Type of voluntary grasping | .449 | | .376 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Coordination upper extr. | | | | | | | | | | | | | | | | | | | | | .370 | | | | | | | | | | | | | |
| Locomotion in prone | | | | | | .455 | | | .404 | .544 | .529 | | | | | | | | | | | | | | | | | -.365 | | | | .354 | | |
| Rolling supine into prone | | | | | | .368 | | | | .358 | .753 | .497 | | .381 | .390 | .386 | .387 | .405 | | | | .374 | .418 | | | .424 | | | | | | | | |
| Rolling prone into supine | | | | | | | | | | | .574 | .639 | | | .396 | | | | | | | | .362 | .384 | | .393 | | | | | | | | |
| Sitting up | | | | | | | | | | | | ,351 | | .411 | | | .377 | .364 | | | | .367 | .403 | | | | | | | | | | | |
| Duration of sitting | | .368 | | .431 | .440 | .499 | | | .383 | .426 | .455 | .382 | | | .695 | .498 | .401 | .423 | | | | .652 | .602 | | | .438 | -.368 | | | | | | | |
| Posture, sitting | | .393 | | .413 | .401 | .478 | | | .364 | .412 | .444 | .357 | | .395 | .685 | .506 | .368 | .399 | | | | .642 | .587 | | | .413 | -.379 | | | | | | | |
| Standing up | | | | .659 | | .798 | .495 | .371 | .690 | .651 | .484 | .396 | | .805 | .594 | .748 | .846 | .871 | .456 | .400 | | .724 | .703 | | .438 | .697 | | | | | | | | |
| Walking | | | | .598 | | .715 | .452 | | .640 | .620 | .543 | .495 | .460 | .812 | .626 | .762 | .820 | .794 | .404 | .426 | | .736 | .717 | | .476 | .697 | | | | | | | | |
| Palmar grasp reflex | .449 | | .376 | | | | | | | | | | | | | | | | .375 | | | | | | | | | | | | | | | |
| Reaction to push, sitting | | .366 | | .420 | .416 | .474 | | | .373 | .381 | .447 | .364 | | | .674 | .480 | .360 | .391 | | | | .628 | .577 | | | .393 | -.376 | | | | | | | |
| Following object, sitting | | .352 | | ,413 | .433 | .501 | | | .374 | .415 | .446 | .380 | | .392 | .682 | .483 | .396 | .411 | | .355 | | .639 | .591 | | | .436 | -.395 | | | | | | | |
| Optical placing hands | | .376 | | | | | | | | | | | | | | | | | | | | | | .358 | | | | | | | | | | |
| Parachute reaction hands | | | | | | | | | | | | | | | | | | | | | | | | .483 | .621 | | | | | | | | | |
| Optical placing feet | | | | .505 | .354 | .733 | | | .461 | .558 | .423 | | | .497 | .363 | .469 | .522 | .600 | | | | .400 | .557 | .369 | .375 | .777 | -.356 | | | | | | .407 | |
| Moro lift abd./ext. | | | | | | | | | | | | | | | | | | | | .363 | | | | | | | | | .361 | .555 | .371 | | | |
| Moro hit abd./ext. | | | | -.361 | | | | -.366 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Rooting | | | | | | | | | | | | | | | | | | | | | | | | .396 | | | | | | | | | | |
| Acoustical orienting | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | .399 |
| Speech | | | | | | | .376 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Appendix F Correlation coefficients ($p \leqq 0.01$) of the interrelationships of the final changes of the items of group III (total group) (Pearson Product-Moment Correlations)

| FINAL CHANGE | Spontaneous post.arms | Spontaneous post.legs | Spontaneous mot.arms | Spontaneous mot.legs. | Sp.mot.legs vert.susp. | Type volunt.grasping | Coord.upper extrem. | Posture prone posit. | Locom. in prone | Rolling sup-prone | Rolling prone-supine | Headlift in supine | Sitting up | Duration of sitting | Posture, sitting | Standing up | Walking | Palmar grasp refl. | Footsole response | React. to push, sitting | Foll.obj. sitting | Opt.placing hands | Parachute react.hands | Opt.placing feet | Moro headdr. abd./ext. | add./flexion | Moro lift abd./ext. | add./flexion | Moro hit abd./ext. | add./flexion | Rooting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spontaneous post.arms | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spontaneous post.legs | | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spontaneous mot.arms | .594 | | x | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Spontaneous mot.legs. | | | | x | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Sp.mot.legs vert.susp. | | | | .653 | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Type volunt.grasping | | | | | | x | | | | | | | | | | | | | | | | | | | | | | | | | |
| Coord.upper extrem. | | | | .413 | | | x | | | | | | | | | | | | | | | | | | | | | | | | |
| Posture prone posit. | | | | .473 | .563 | .496 | | x | | | | | | | | | | | | | | | | | | | | | | | |
| Locom. in prone | | | | .494 | .647 | .378 | | .506 | x | | | | | | | | | | | | | | | | | | | | | | |
| Rolling sup-prone | | | | .468 | .485 | | | .462 | .433 | x | | | | | | | | | | | | | | | | | | | | | |
| Rolling prone-supine | | | | .567 | .389 | | | | .409 | .488 | x | | | | | | | | | | | | | | | | | | | | |
| Headlift in supine | | | | | | | | | .461 | | | x | | | | | | | | | | | | | | | | | | | |
| Sitting up | | | | .548 | .665 | .474 | | .678 | .652 | .475 | .482 | .374 | x | | | | | | | | | | | | | | | | | | |
| Duration of sitting | | .437 | | .485 | .464 | | | .451 | .460 | .412 | .401 | | .634 | x | | | | | | | | | | | | | | | | | |
| Posture, sitting | | | | .559 | .580 | .559 | .386 | .617 | .601 | .495 | .444 | .391 | .842 | .707 | x | | | | | | | | | | | | | | | | |
| Standing up | | | | ,512 | .717 | .378 | | .679 | .641 | .464 | .393 | | .803 | .612 | .644 | x | | | | | | | | | | | | | | | |
| Walking | | | | .562 | .800 | .439 | .359 | .726 | .600 | .483 | | | .747 | .546 | .672 | .890 | x | | | | | | | | | | | | | | |
| Palmar grasp refl. | .420 | | | | .478 | | | | | | | | | | | .422 | .374 | x | | | | | | | | | | | | | |
| Footsole response | | | | | .371 | | | | | | | | | .423 | | .409 | .376 | | x | | | | | | | | | | | | |
| React. to push, sitting | | .394 | | .474 | .575 | .395 | | .561 | .559 | .503 | .450 | .366 | .787 | .886 | .831 | .721 | .662 | | .383 | x | | | | | | | | | | | |
| Foll.obj. sitting | | .357 | | .469 | .535 | .458 | | .540 | .495 | .423 | .474 | | .780 | .913 | .825 | .700 | .643 | | .400 | .947 | x | | | | | | | | | | |
| Opt.placing hands | | .400 | | .402 | | | | .369 | | | | | | | | .386 | | | | | | x | | | | | | | | | |
| Parachute react.hands | | | | .358 | .486 | | | | | | | | | | | .380 | .452 | | .395 | | | .483 | x | | | | | | | | |
| Opt.placing feet | | | | .515 | .675 | | | .439 | .597 | .476 | .376 | ,359 | .609 | .478 | .475 | .644 | .621 | | .451 | .456 | .444 | .385 | ,411 | x | | | | | | | |
| Moro headdr. abd./ext. | | | | | | | | | | | | | | | | | | | | | | | | | x | | | | | | |
| add./flexion | | | | | | | | | | | | | | | | | | | | | | | | | .617 | x | | | | | |
| Moro lift abd./ext. | | | | | | | | | | | | | | | | | | | | | | | | | | | x | | | | |
| add./flexion | | | | | | | | | | | | | | | | | | | | | | | 4.35 | | | .572 | | x | | | |
| Moro hit abd./ext. | | | | | | | | | | | | | | | | | | | | | | | | | | .372 | .502 | .371 | x | | |
| add./flexion | | | | | | | | | | | | | | | | | | | | | | | | | | | .536 | .391 | .753 | x | |
| Rooting | | | | | | .412 | | | | | | | | | | | | | | | | | | | | | | | | | x |

Appendix E Correlation coefficients (p ≦ 0.01) of the interrelationships of the first changes of the items of group III (total group) (Pearson Product-Moment Correlations)

| FIRST CHANGE | Spontaneous post.arms | Spontaneous post.legs | Spontaneous mot.legs | Goal-dir. motility arms | Type of vol.grasping | Coord.upper extrem. | Post.in prone posit. | Locomotion in prone | Rolling sup-prone | Rolling pr.supine | Duration of sitting | Posture sitting | Standing up | Walking | Asym.ton.neck. imposed. | Asymm.ton.neck. spon. | Resp. to push, sitting | Foll.obj. sitting | Opt.placing hands | Opt.placing feet | Moro headdr. abd./ext. | Moro lift abd./ext. | Rooting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spontaneous post.arms | X | | | | | | | | | | | | | | | | | | | | | | |
| Spontaneous post.arms | | X | | | | | | | | | | | | | | | | | | | | | |
| Spontaneous mot.legs | .385 | | X | | | | | | | | | | | | | | | | | | | | |
| Goal-dir. motility arms | | .365 | | X | | | | | | | | | | | | | | | | | | | |
| Type of vol.grasping | | | | | X | | | | | | | | | | | | | | | | | | |
| Coord.upper extrem. | | | | .392 | 371 | X | | | | | | | | | | | | | | | | | |
| Post.in prone posit. | | | | .390 | | | X | | | | | | | | | | | | | | | | |
| Locomotion in prone | | | | | | | | X | | | | | | | | | | | | | | | |
| Rolling sup-prone | | | | | | | | .436 | X | | | | | | | | | | | | | | |
| Rolling pr.supine | | | | | | | | | 605 | X | | | | | | | | | | | | | |
| Duration of sitting | | | | | | | | .396 | 490 | .429 | X | | | | | | | | | | | | |
| Posture sitting | | | | | | | | .391 | 478 | .413 | .993 | X | | | | | | | | | | | |
| Standing up | | | | | | | | | .361 | | .419 | .384 | X | | | | | | | | | | |
| Walking | | | | | | | | | .497 | 472 | .399 | .370 | .897 | X | | | | | | | | | |
| Asym.ton.neck. imposed. | | .411 | | | | | | | | | | | | | X | | | | | | | | |
| Asymm.ton.neck. spon. | | | | | | 379 | | | | | | | | | .862 | X | | | | | | | |
| Resp. to push, sitting | | | | | | | | | .483 | .409 | .989 | .989 | .385 | .367 | | | X | | | | | | |
| Foll.obj. sitting | | | | | | | | .400 | .493 | .421 | .993 | .986 | .420 | .392 | | | .990 | X | | | | | |
| Opt.placing hands | | | | | | | .412 | .452 | | | | | | | | | | | X | | | | |
| Opt.placing feet | | | | | | | | .389 | .388 | | .486 | .466 | .658 | .591 | | | .470 | .499 | | X | | | |
| Moro headdr. abd./ext. | .544 | | | | | | | | | | | | | | | | | | 408 | -.360 | X | | |
| Moro lift abd./ext. | | | | | | -.398 | | | | | | | | | | | | | | | | X | |
| Rooting | | | | | | | | | | | | | | | | | | | .403 | | | | X |

**Appendix G:** Correlation coefficients ($p \leqq 0.01$) of the interrelationships of the developmental ranges of the items of group III (total group) (Pearson Product-Moment Correlations).

| DEVELOPMENTAL RANGE | Spontaneous post.arms | Spontaneous mot.legs | Spont.mot.legs vert.susp. | Type of volunt.grasping | Coord.upper extrem. | Post.prone position | Locom.in prone | Headlift in supine | Sitting up | Duration of sitting | Posture, sitting | Standing up | Footsole response | React. to push, sitting | Foll.obj.sitting | Opt.placing hands | Parachute react.hands | Opt.placing feet | Moro lift, abd./ext. | Moro hit, abd./ext. | Rooting |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Spontaneous post.arms | X | | | | | | | | | | | | | | | | | | | | |
| Spontaneous mot.legs | .359 | X | | | | | | | | | | | | | | | | | | | |
| Spont.mot.legs vert.susp. | | .554 | X | | | | | | | | | | | | | | | | | | |
| Type of volunt.grasping | | | | X | | | | | | | | | | | | | | | | | |
| Coord.upper extrem. | | | | | X | | | | | | | | | | | | | | | | |
| Post.prone position | .394 | .504 | .515 | .415 | | X | | | | | | | | | | | | | | | |
| Locom.in prone | | | | .366 | | | X | | | | | | | | | | | | | | |
| Headlift in supine | | | | | | | | X | | | | | | | | | | | | | |
| Sitting up | | 415 | | | | .454 | 566 | 374 | X | | | | | | | | | | | | |
| Duration of sitting | | | | | | | | | | X | | | | | | | | | | | |
| Posture, sitting | | | | .406 | | | | | 459 | .694 | X | | | | | | | | | | |
| Standing up | | | | | | 368 | | | | | | X | | | | | | | | | |
| Footsole response | | | | | | .378 | 359 | | 395 | | | | X | | | | | | | | |
| React. to push, sitting | | | | | | | | | | .836 | .836 | | | X | | | | | | | |
| Foll.obj.sitting | | | | | | | | | | .892 | .840 | | | .934 | X | | | | | | |
| Opt.placing hands | | | | | | 367 | | | | | | | | | | X | | | | | |
| Parachute react.hands | | | 461 | | | | | | | | | | | | | | X | | | | |
| Opt.placing feet | | | | | | | | | | | | | .408 | | | | | X | | | |
| Moro lift, abd./ext. | | | | | | | | | | | | | | | | | | | X | | |
| Moro hit, abd./ext. | | | | | | | | | | | | | | | | | .377 | | 377 | X | |
| Rooting | | | | | 419 | | | | | | | | | | | | | | | | X |

| Final change | | | | dev.range | | | | inconsistencies | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | sigma | Skew-ness | Kur-tosis | Mean | sigma | Skew-ness | Kur-tosis | Mean | sigma | Skew-ness | Kur-tosis |
| 5.00 | 1.137 | 0.516 | 2.93 | 2.41 | 1.485 | 0.354 | 2.47 | 0.24 | 0.480 | 1.742 | 5.16 |
| 10.04 | 1.541 | 0.138 | 2.31 | 7.78 | 1.598 | 0.217 | 2.17 | 1.00 | 0.791 | 0.511 | 2.94 |
| 4.78 | 1.141 | 0.363 | 3.12 | 2.78 | 1.141 | 0.363 | 3.12 | 0.14 | 0.354 | 2.041 | 5.17 |
| 12.08 | 1.605 | 0.477 | 3.36 | 9.14 | 1.803 | 0.043 | 2.78 | 0.51 | 0.582 | 0.602 | 2.38 |
| 14.12 | 2.058 | 0.312 | 3.12 | 11.39 | 2.289 | 0.141 | 2.82 | 2.24 | 0.969 | 0.050 | 2.45 |
| 13.47 | 2.459 | 0.041 | 3.26 | 10.20 | 2.475 | 0.047 | 2.91 | 0.49 | 0.582 | 0.681 | 2.47 |
| 13.29 | 1.594 | 0.427 | 2.79 | 8.80 | 1.871 | 0.281 | 2.62 | 0.43 | 0.540 | 0.687 | 2.28 |
| 10.71 | 1.607 | 0.017 | 2.86 | 4.16 | 1.929 | 0.856 | 4.62 | 0.67 | 0.774 | 1.174 | 4.31 |
| 12.16 | 2.230 | 0.613 | 3.89 | 8.65 | 2.350 | 0.170 | 2.92 | 1.12 | 0.807 | 0.257 | 2.51 |
| 13.73 | 1.998 | -0.231 | 2.82 | 6.53 | 1.685 | 0.105 | 2.15 | 0.55 | 0.647 | 0.740 | 2.52 |
| 7.59 | 1.848 | 1.555 | 6.86 | 0.84 | 1.214 | 2.931 | 14.78 | 0.10 | 0.368 | 3.794 | 17.37 |
| 8.06 | 1.345 | 0.251 | 3.86 | 1.12 | 1.201 | 0.929 | 2.96 | 0.29 | 0.577 | 1.875 | 5.41 |
| 8.39 | 1.539 | -0.116 | 2.73 | 1.16 | 1.028 | 0.833 | 3.50 | 0.14 | 0.408 | 2.917 | 11.19 |
| 12.45 | 1.757 | 0.225 | 3.74 | 6.27 | 1.729 | -0.147 | 2.55 | 0.61 | 0.671 | 0.628 | 2.34 |
| 11.65 | 1.508 | 0.385 | 3.07 | 2.45 | 1.243 | 0.875 | 3.26 | 0.14 | 0.354 | 2.041 | 5.27 |
| 12.35 | 1.640 | 0.461 | 3.25 | 3.18 | 1.642 | 0.958 | 4.44 | 0.22 | 0.468 | 1.916 | 5.87 |
| 16.37 | 2.243 | 0.092 | 2.65 | 4.10 | 1.246 | 0.067 | 2.08 | 0.04 | 0.200 | 4.641 | 22.54 |
| 18.00 | 2.380 | 0.056 | 3.12 | 4.57 | 1.472 | 0.373 | 4.01 | 0.04 | 0.200 | 4.641 | 22.54 |
| | | | | | | | | | | | |
| 12.92 | 1.812 | 0.335 | 3.06 | 4.37 | 2.038 | 0.760 | 3.06 | 1.04 | 1.117 | 0.825 | 2.65 |
| 5.59 | 1.134 | 0.111 | 2.75 | 3.51 | 1.362 | 0.123 | 2.77 | 0.35 | 0.522 | 1.035 | 2.93 |
| 8.18 | 1.244 | -1.282 | 7.51 | 6.18 | 1.438 | -0.924 | 5.16 | 0.78 | 0.757 | 0.654 | 2.93 |
| 8.69 | 1.310 | 0.076 | 2.01 | 3.06 | 1.329 | 0.532 | 3.08 | 0.27 | 0.491 | 1.585 | 4.57 |
| 12.12 | 1.467 | 0.507 | 4.45 | 2.94 | 1.391 | 0.392 | 2.36 | 0.08 | 0.277 | 3.056 | 10.34 |
| 11.96 | 1.443 | 0.618 | 4.74 | 2.71 | 1.414 | 0.561 | 2.46 | 0.18 | 0.391 | 1.634 | 3.67 |
| 10.29 | 1.514 | 0.999 | 5.85 | 2.02 | 1.507 | 1.405 | 6.56 | 0.16 | 0.373 | 1.822 | 4.32 |
| 12.51 | 2.247 | 0.315 | 3.58 | 2.55 | 1.780 | 0.341 | 2.23 | 0.97 | 0.865 | 0.468 | 2.35 |
| 12.94 | 1.819 | 0.427 | 2.92 | 1.37 | 1.131 | 0.639 | 2.51 | 0.29 | 0.500 | 1.443 | 4.08 |
| 13.61 | 2.790 | 0.249 | 2.58 | 4.94 | 3.256 | 0.469 | 2.63 | 1.57 | 1.118 | 0.0 | 1.98 |
| 6.45 | 0.937 | 0.380 | 2.88 | 1.51 | 0.893 | 0.235 | 3.07 | 0.10 | 0.306 | 2.629 | 7.91 |
| 3.06 | 1.126 | 0.942 | 3.13 | — | — | — | — | 0.27 | 0.531 | 1.866 | 5.58 |
| 4.06 | 1.314 | 0.221 | 2.25 | 1.55 | 1.276 | 0.341 | 2.06 | 0.41 | 0.537 | 0.779 | 2.42 |
| 5.73 | 1.934 | 0.311 | 4.20 | — | — | — | — | 0.69 | 0.683 | 0.461 | 2.20 |
| 10.73 | 1.890 | 0.668 | 3.41 | 4.94 | 2.045 | 0.128 | 2.95 | 0.90 | 0.872 | 0.769 | 2.97 |
| 7.12 | 1.943 | 0.463 | 3.80 | — | — | — | — | 1.14 | 0.890 | 0.256 | 2.22 |
| 7.06 | 1.533 | 1.053 | 6.03 | 2.78 | 2.114 | 1.141 | 6.11 | 0.71 | 0.736 | 0.498 | 2.01 |
| 12.22 | 1.896 | 1.008 | 5.45 | 9.71 | 1.904 | 1.001 | 4.76 | 0.16 | 0.373 | 1.822 | 4.32 |

**Appendix J:** Variation ranges of the first and the final changes and the number of inconsistencies of the items of group III (total group).
The number of infants with inconsistencies, the length of the scoring scale and the maximum number of scores found at a single assessment are also presented.

Key: a: maximal variation range of the first change
b: maximal variation range of the final change
c: number of infants with inconsistencies
d: number of inconsistencies
e: length of the scoring scale
f: maximal number of scores at one examination

| Items | a | b | c | d | e | f |
|---|---|---|---|---|---|---|
| **Observation of posture and motility** | | | | | | |
| spontaneous posture of the arms | 2- 6 | 3- 8 | 12 | 13 | 4 | 4 |
| spontaneous posture of the legs | 2- 4 | 7-13 | 38 | 52 | 4 | 4 |
| spontaneous motility of the arms | 2 | 3- 8 | 7 | 7 | 5 | 4 |
| spontaneous motility of the legs | 2- 5 | 9-16 | 24 | 36 | 4 | 3 |
| spontaneous motility of the legs in vertical suspension | 2- 5 | 9-19 | 50 | 113 | 6 | 6 |
| goal-directed motility of the arms and hands | 2- 4 | 8-19 | 22 | 24 | 7 | 5 |
| type of voluntary grasping | 3- 6 | 10-17 | 21 | 22 | 7 | 5 |
| coordination of the upper extremities | 4- 9 | 7-15 | 27 | 36 | 3 | 3 |
| posture of head, trunk and arms in prone position | 2- 5 | 7-19 | 40 | 59 | 7 | 6 |
| locomotion in prone position | 4-11 | 9-18 | 23 | 27 | 6 | 6 |
| rolling over from supine into prone position | 4-11 | 5-15 | 4 | 5 | 3 | 3 |
| rolling back from prone into supine position | 4-11 | 5-12 | 12 | 15 | 4 | 4 |
| spontaneous head lift in supine position | 4-10 | 5-12 | 6 | 7 | 3 | 3 |
| sitting up | 4-10 | 8-17 | 26 | 31 | 4 | 4 |
| duration of sitting | 6-13 | 9-16 | 7 | 7 | 5 | 5 |
| posture of the trunk during sitting | 6-13 | 9-17 | 10 | 11 | 5 | 5 |
| standing up | 3-16 | 11-21 | 2 | 2 | 5 | 5 |
| walking | 10-19 | 12-24 | 2 | 2 | 5 | 5 |
| **Reactions and Responses** | | | | | | |
| rooting | 7-11 | 9-17 | 29 | 54 | 5 | 5 |
| asymmetric tonic neck response — imposed | 1- 4 | 3- 8 | 17 | 18 | 3 | 3 |
| — spontaneous | 1- 4 | 6-11 | 30 | 38 | 3 | 3 |
| palmar grasp reflex | 3 7 | 6-11 | 12 | 13 | 3 | 3 |
| reaction to push against the shoulder, when sitting | 6-13 | 9-17 | 4 | 4 | 4 | 4 |
| following an object with the eyes, and with rotation of the head and trunk, when sitting | 6-13 | 9-17 | 9 | 9 | 5 | 5 |
| optical placing reaction of the hands | 6-11 | 7-16 | 8 | 8 | 3 | 3 |
| parachute reaction of arms and hands in prone suspension | 5-14 | 7-19 | 33 | 48 | 3 | 3 |
| optical placing reaction of the feet | 8-16 | 9-18 | 14 | 16 | 3 | 3 |
| foot sole response | 2-15 | 8-20 | 39 | 79 | 3 | 3 |
| acoustical orienting | 3- 7 | 5- 9 | 6 | 6 | 3 | 3 |
| Moro — headdrop, abduction/extension | 2- 5 | 2- 6 | 19 | 20 | 3 | 3 |
| adduction/flexion | 2- 4 | 2- 6 | 11 | 13 | 3 | 3 |
| lift, abduction/extension | 2- 9 | 7-16 | 32 | 46 | 4 | 4 |
| adduction/flexion | 2- 5 | 1-12 | 30 | 37 | 3 | 3 |
| hit on surface, abduction/extension | 2- 8 | 4-13 | 28 | 37 | 3 | 3 |
| adduction/flexion | 2- 7 | 3-13 | 38 | 59 | 4 | 4 |

Appendix H: Correlation coefficients ($p \leqq 0.01$) of the relationships between the developmental ranges and the number of inconsistencies of the items of group III (total group) (Spearman Rank Correlations).

| | |
|---|---|
| Parachute reaction of the hands | .661 |
| Optical placing reaction of the feet | .637 |
| Moro, hit, abduction/extension | .634 |
| Rooting | .603 |
| Moro, headdrop, abduction/extension | .590 |
| Footsole response | .564 |
| Optical placing reaction of the hands | .477 |
| Rolling over from supine into prone position | .461 |
| Asymmetric tonic neck response, spontaneous | .458 |
| Type of voluntary grasping | .440 |
| Moro lift, abduction/extension | .421 |
| Coordination of upper extremities | .377 |